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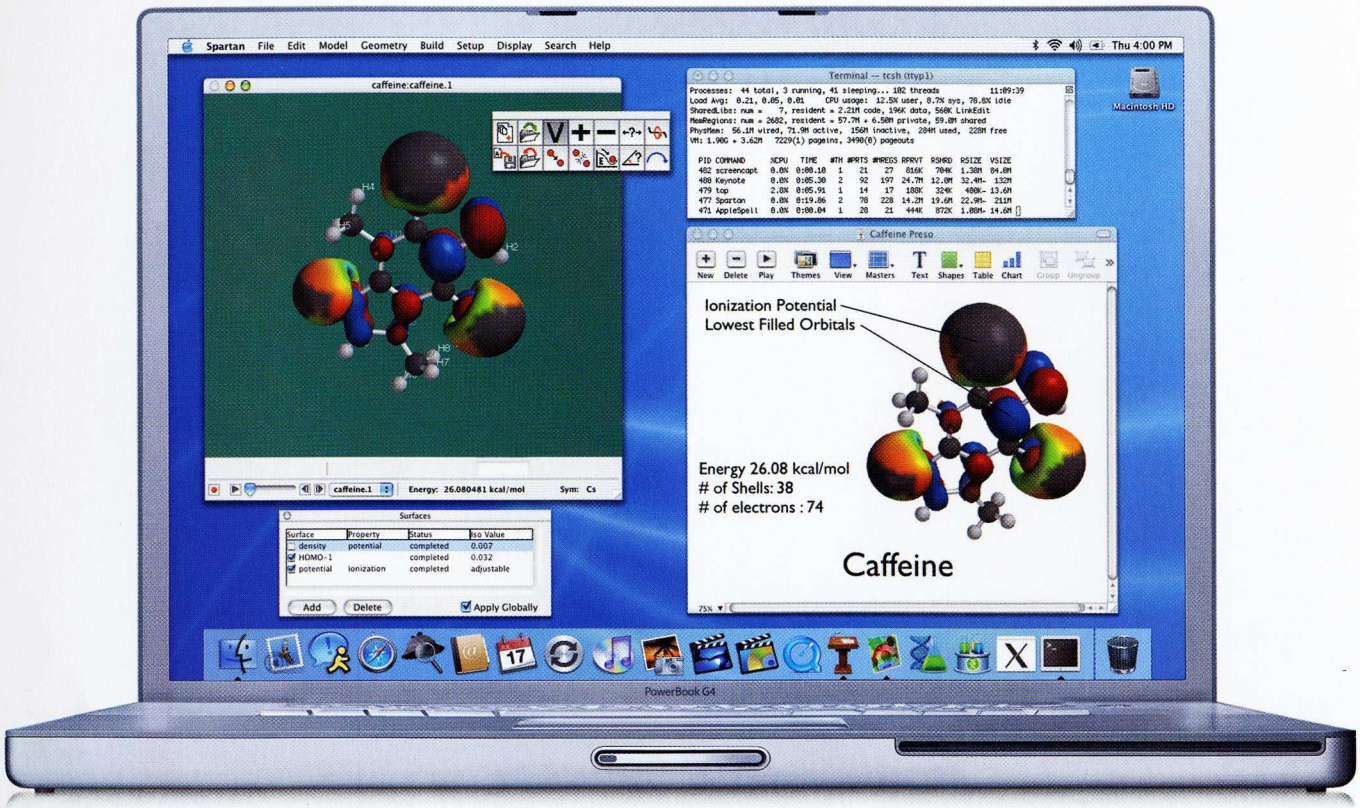
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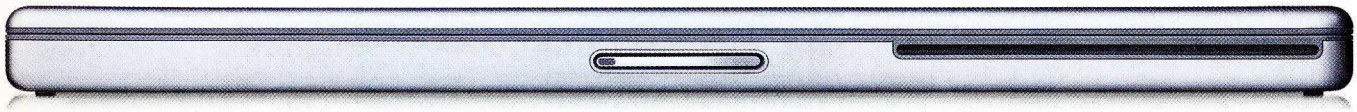
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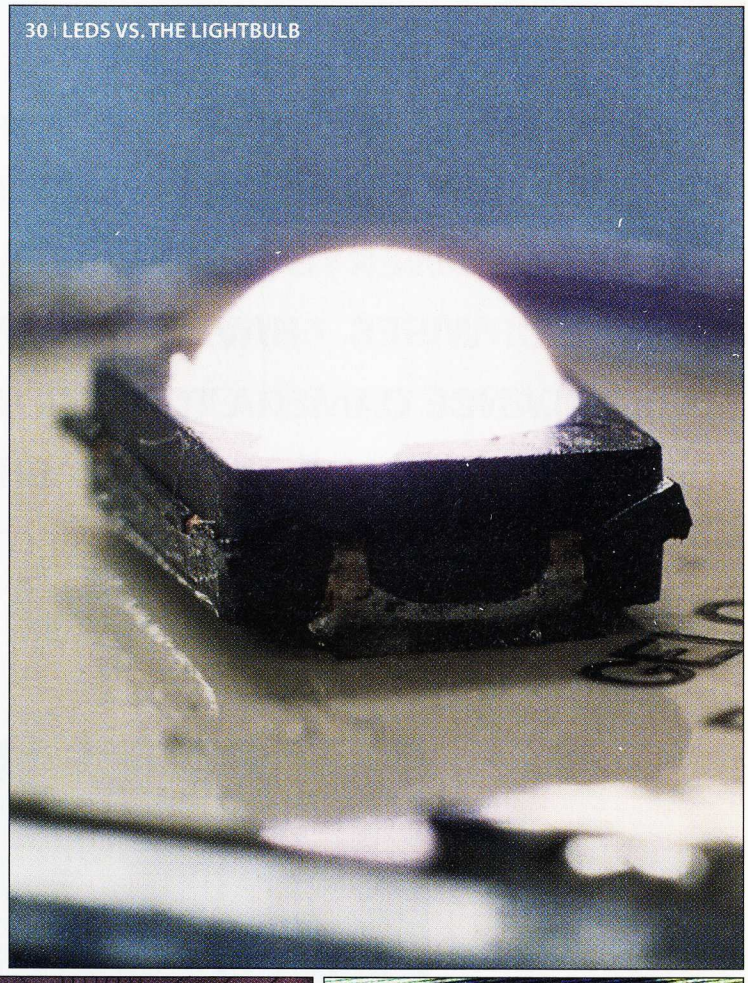
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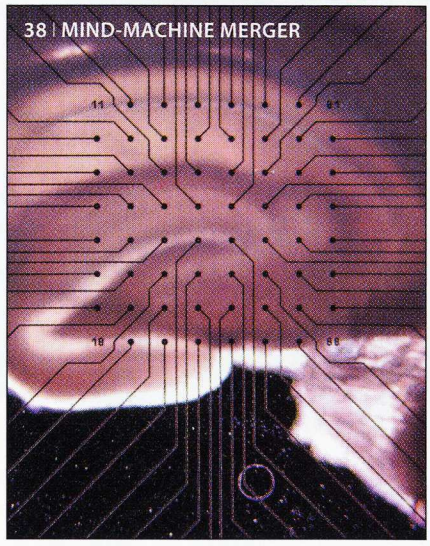
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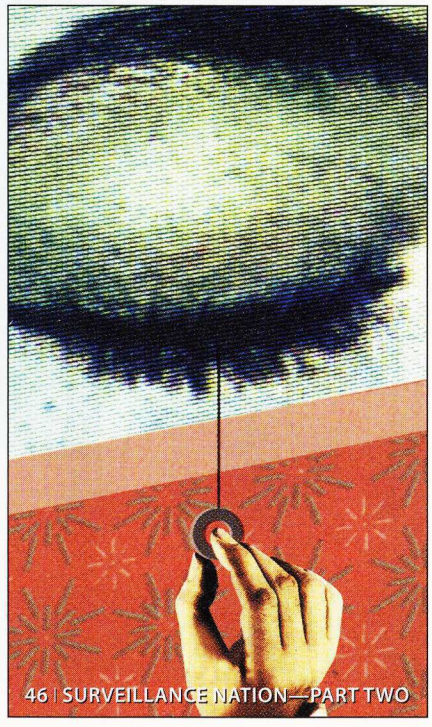
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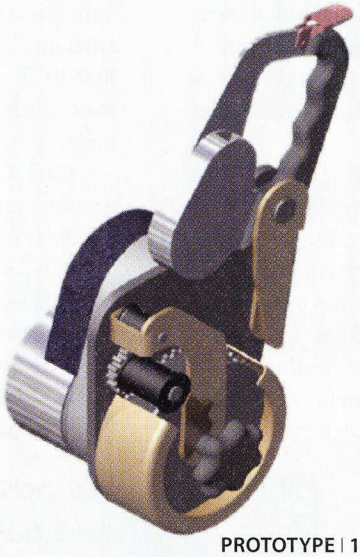
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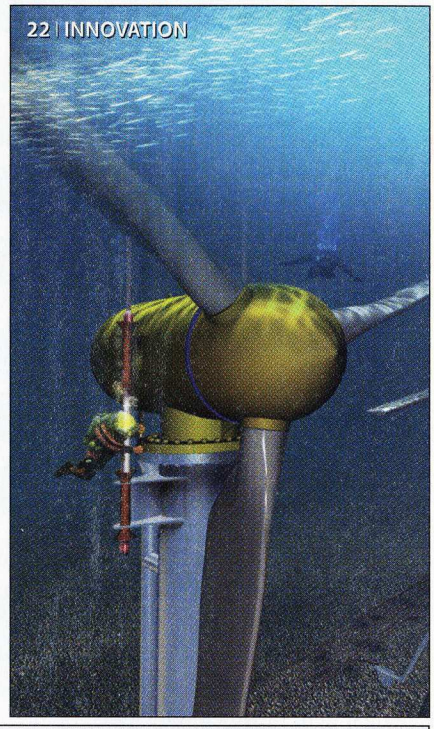
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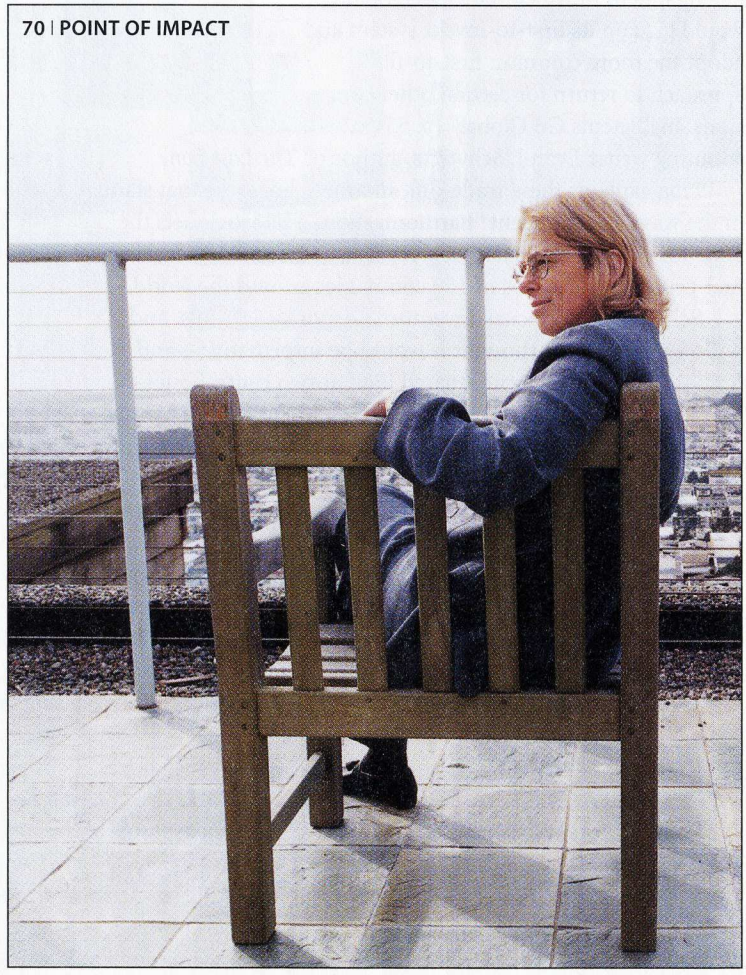
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SHOULD PATENTS GO GLOBAL?

As just about every nation has recognized, protecting the intellectual-property rights of inventors is essential to promoting innovation and ensuring economic growth. But the world is divided over which elements should determine whether an invention warrants a patent and who has legitimate rights to that patent. And on this issue—surprise—the United States finds itself alone.

The U.S. system awards a patent to the first person who invents a given thing, as proved by such evidence as witnessed lab notebooks. In nearly every other country, though, a patent goes to the first person who shows up at a patent office to file a claim. But there are many other divisive issues as well—including the very idea of what may be patented.

The globalization of business markets has heightened the need to secure patents for each invention in many nations. Filing and maintaining these multiple claims is expensive even for large companies; for independent inventors, the costs can be downright oppressive. Now, though, momentum is building for a global patent system in which the United States would give up its first-to-invent system and adopt the more common first-to-file approach in return for certain other concessions. In "Patents Go Global" *(p. 55)*, contributing writer Evan I. Schwartz, author of *The Last Lone Inventor*, explains these trade-offs and the roadblocks that stand in the way of such patent "harmonization." His article sets the stage for our annual Patent Scorecard, which tracks the intellectual-property portfolios of 150 companies around the world.



We posed two questions to inventors and patent experts: What's most wrong with the U.S. patent system? Would you give up that process for the efficiencies of a global patent system?

Schwartz's piece cites inventors, corporate officials, and policymakers. But I thought it would be informative—and fun—to take a more opinionated look at two central questions: What's most wrong with the U.S. patent system? Would you give up the U.S. first-to-invent process for the efficiencies of a global patent system?

Schwartz and I posed these questions to leading inventors and patent experts. Excerpts from their answers:

Robert Langer, MIT chemical and biomedical engineering professor; winner of the 1998 Lemelson-MIT Prize, which recognizes America's outstanding contemporary inventors:

What's wrong? "It would be good if the U.S. process were faster."

Go global? "First-to-invent is correct because it recognizes who really did it first."

Seth Shulman, *Technology Review* columnist and author of *Owning the Future*:

What's wrong? "We've steadily moved up the ladder of abstraction to a point where it represents a perversion of the patent system. The system works great for protecting an inventor's right to a new type of mousetrap. What's increasingly happening today, though, is that the U.S. Patent Office is letting crafty applicants essentially patent the idea of trapping mice."

Go global? "The first-to-invent system is hands-down the best way to go. But I would grudgingly give up the U.S. system: it is deeply flawed in practice; the gain in simplicity and efficiency from a global system could be significant; and the first-to-file approach takes the onus off the government to make determinations about the evolution of technological innovation and in a sense moves it to the marketplace."

Carl R. Crawford, inventor; technical vice president, Analogic, an electronics maker in Peabody, MA; holder or coholder of 132 patents worldwide:

What's wrong? "Short of perpetual-motion machines, it is possible to get a patent on almost anything. This effectively pushes the question of inventiveness onto the courts, where the sole inventor has a disadvantage."

Go global? "First-to-invent causes inventors to file more 'garbage' patents. If political and national bias could be removed from the global patent process, then a global patent office would be acceptable."

Bernard S. Meyerson, IBM fellow and chief technologist, IBM Technology Group:

What's wrong? "The greatest challenge faced by the U.S. patent system is the apparent lack of adequate funding and staffing required to perform thorough investigations."

Go global? "The U.S. should adopt a first-to-file system—but only as part of a full-harmonization effort with other countries."

Nathan Myhrvold, former Microsoft chief technology officer; cofounder, Intellectual Ventures in Bellevue, WA:

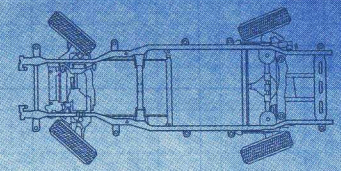
What's wrong? "In most parts of computer science, the rate at which patents are filed is up by a factor of 10 since 1990. Biotech is up even more. The patent office has a real problem trying to cope with that."

Go global? "It's like driving on the right or the left side of the road. Either one [first-to-file or first-to-invent] works just fine: if you try to mix the two, you get a problem. And so the issue is not which one is better; it's that making the change is going to be wrenching."

The devil, of course, will be in the details. But wrenching though the change may be, it is what needs to happen. The U.S. might even find that going along with the rest of the world will bring unexpected benefits. —*Robert Buderi*



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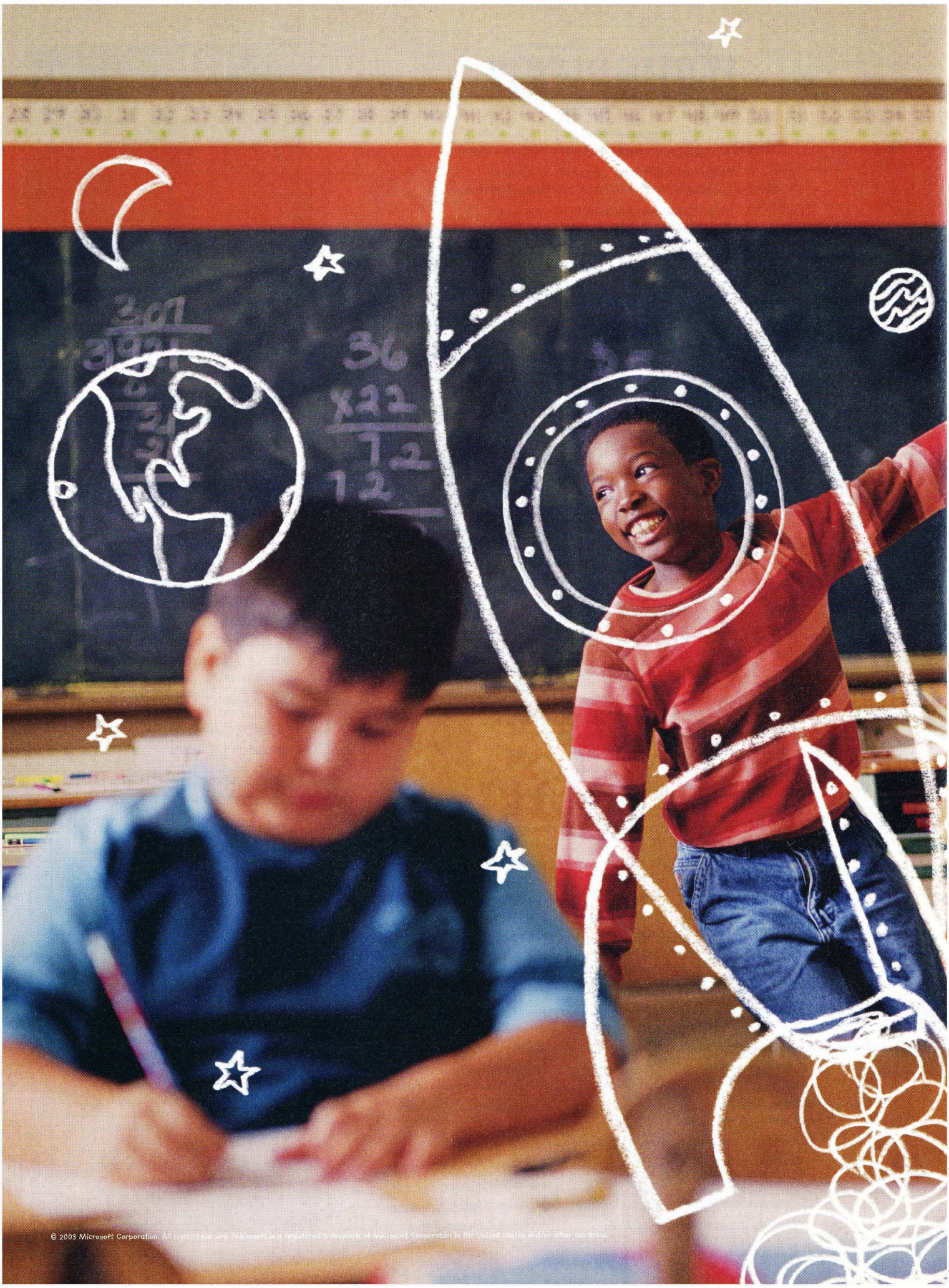
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LETTERS

INSIGHTS AND OPINIONS FROM OUR READERS

MAKING SENSE OF 'SENSEMAKING'

The juxtaposition of information technologies for homeland security in M. Mitchell Waldrop's article ("Can Sensemaking Keep Us Safe?" *TR* March 2003) reveals a conceptual flaw. On the one hand, Waldrop argues for the need to integrate information from many sources without centralizing control over it. This would imply that no single agency would have access to the whole collection of data. On the other hand, the article also proposes making sense of the information via a prior step of taxonomy building—a step that would be possible only if an entire body of information were centrally amassed. In other words, a taxonomy-building approach conflicts with decentralization.

Raul Valdes-Perez
Pittsburgh

Waldrop cites a reluctance of various agencies to share sensitive information. This is not an unjustified concern. One of the most important things to know about any threat-detection system should be who is accessing it and why. How do we assure that the information will not be misused? A system that records a complete history of data—what was requested, by whom, and when—could help us detect dangerous abusers and would perhaps be more acceptable to investigative organizations guarding their informational turf.

Jim Laurino
Philadelphia

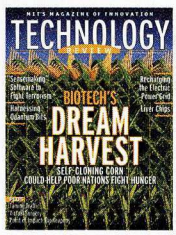
MISSILE DEFENSE DEFENDED

Robert Buderi's column in support of missile defense R&D ("Leading Edge," *TR* March 2003) is a brave statement that has needed saying for some time. The slings and arrows are surely on their way.

Rudy Ressler
Olympia, WA

Buderi's rationalization for developing a missile defense technology is not convincing. A missile defense system wouldn't have prevented September 11. Our defense against future threats will rely more on diplomacy than on building a strategic dome over the country. The only smart approach to missile defense is to scrap this failed, wasteful government boondoggle held over from the cold war. The billions of dollars being spent on this project would be better spent on technology and education instead of an ideological weapon that doesn't work against a threat that doesn't exist.

Baron Lane
San Antonio



"Successful missile defense of the United States demands that multiple components, many still unproven, work together in near perfection to achieve the desired objective."

Instead of trying to completely protect ourselves from intercontinental ballistic missiles and cruise missiles, wouldn't it make more sense—and save an enormous amount of money—to adopt a policy of destroying, after fair warning, any facility on foreign soil that our intelligence indicates has the capability of launching such weapons? Our satellite-based imaging systems are already in place; our drones and similar weapons have shown they work.

Thomas C. Ehlert
Milwaukee

Buderi draws a faulty analogy between the missile defense program and the development of radar prior to World War II. Radar gave the British defenders all-weather capability to detect approaching German aircraft. With the advantage of early warning, fighter interceptors—a proven defense system—were able to win the war of attrition against the German bomber fleet. In contrast, successful missile defense of the United States demands that multiple components, many still unproven, work together in near perfection to achieve the desired objective.

Steven M. Sussman
Littleton, MA

Your column on missile defense is excellent. Any discussion of this topic must assume a range of political and technological possibilities and probabilities. At the maximum, we have to plan counters to a major nuclear attack and even Earth's collision with an asteroid. At the minimum, we should be prepared to deal with a rogue attack from a lunatic. Identifying an appropriate response for such a wide range of situations is a major part of the problem.

Joe Salmon
Dothan, AL

CLONED CORN

Daniel Charles's suggestion that Pioneer is somehow threatened by the potential use of apomixis technology ("Corn That Clones Itself," *TR* March 2003) is not true. Pioneer plans to utilize this technology to make our hybrid production more efficient. Apomixis also has the potential to help developing countries that do not have the infrastructure for hybrid-seed production. This is one reason we are collaborating with CIMMYT, offering expertise, funding, and in-kind research.

Anthony Cavalieri
Pioneer Hi-Bred International
Johnston, IA

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RECHARGING THE POWER GRID

The flow batteries described in Peter Fairley's article ("Recharging the Power Grid," *TR* March 2003) might be a reasonable solution to blackout problems at Columbus Air Force Base, but not for the utility industry in general. The inefficiency of flow batteries causes the overall efficiency to go down. A typical application, where half of the power comes from the battery and half directly from the power plant, requires 30 percent more electricity. This requires 30 percent more fuel. How is this going to help solve our fossil fuel dependency problem?

Greg Schaffer
Cupertino, CA

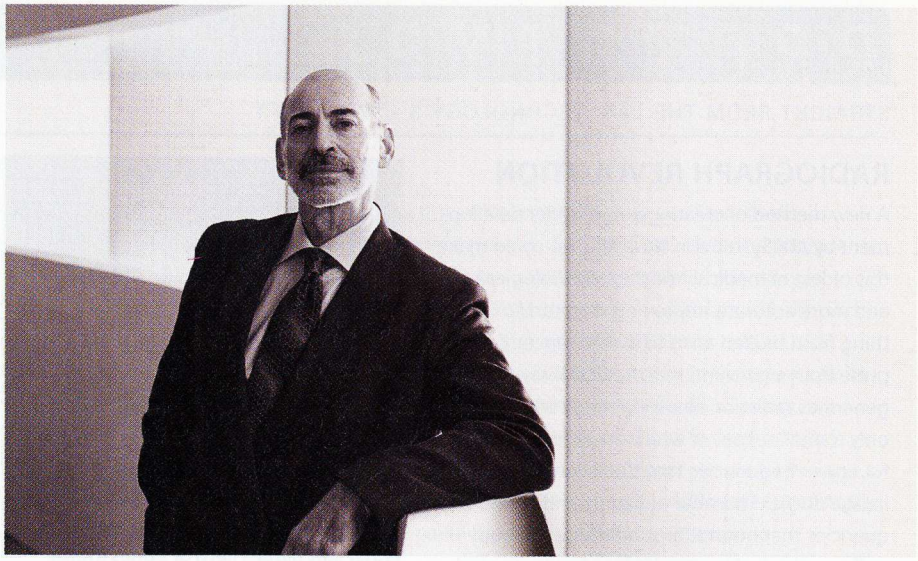
Your interesting article on the electric power grid suggests another approach, involving pumped storage. Suppose that a utility sets up an electrolysis plant to separate hydrogen from oxygen. It sells the oxygen and then the hydrogen is piped up to a high hill where it is burned to generate electricity. Not much pumping power is required. The by-product, water, runs downhill to generate hydropower at strategic times. Finally, the water is sold for irrigation. In addition, some heavy hydrogen might be recovered. Could this achieve several desirable objectives economically?

Charles I. Clausing
Medford, NJ

ONLINE FORUMS

Thank you, Michael Schrage, for writing about something that has irritated me for years ("Flaming Ideas, *TR* March 2003). I've participated in the forums offered by several newspapers, magazines, and Web sites, but I became disenchanted by the poor grammar, bad spelling, and irrelevance of the commentary—to say nothing of the name-calling. You said what I have always wanted to say, and you said it well. I hope your comments don't fall on deaf ears.

Leonard A. Magazine
Battle Ground, WA



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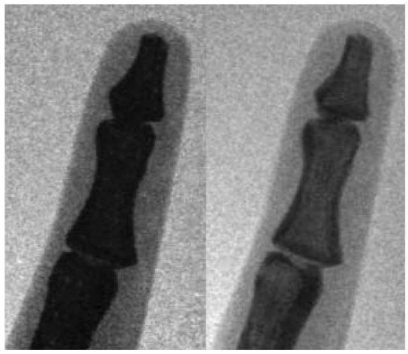
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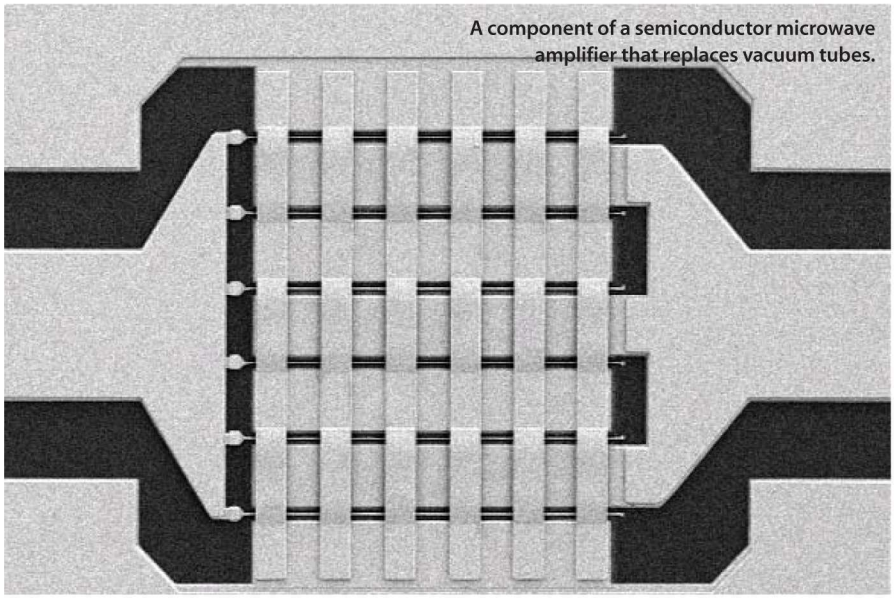
RADIOGRAPH REVOLUTION

A new method of creating x-rays under development by MXISystems in Nashville, TN, could make this oldest of medical imaging technologies safer and more accurate, improving diagnosis of everything from broken arms to breast cancer. Each pulse from a conventional medical x-ray machine generates radiation at a wide range of frequencies, only a small subset of which are diagnostically useful. Lower frequencies that don't contribute to the image do yield harmful radiation, and higher frequencies that bounce around inside the body blur radiographs, making the images harder to read.



Different x-ray frequencies highlight either soft tissues (left) or bones (right).

MXISystems' machine produces x-rays that span an extremely narrow frequency band; its emission can be tuned to the frequency best suited for each specific imaging task—a chest x-ray, say, or a mammogram. The system works by colliding a beam of electrons with an infrared laser beam; their interaction creates x-rays at a frequency that is related to the speed of the electrons, which can be easily adjusted. Based on technology from Vanderbilt University's W.M. Keck Free-Electron Laser Center, the machine emits less harmful radiation than standard x-ray units. It also produces high-resolution radiographs with sharper contrast between tissues of different densities, making it easier to distinguish tumors from healthy tissue, for example. The company plans to begin trials of the machine for mammography next year.



A component of a semiconductor microwave amplifier that replaces vacuum tubes.

MINIMICROWAVE

Communications devices use microwaves, which are tricky to amplify. Vacuum tube hardware weighing hundreds of kilograms is needed to produce the highest-power signals for military radar. Semiconductor devices made of silicon or gallium arsenide work well for the few-kilometer transmissions required by cell phones, but they have too little power to send signals over long distances. A new microwave amplifier built at General Electric's Global Research Center in Niskayuna, NY, packs the amplifying power of vacuum tubes into a semiconductor package. GE developed techniques for reducing defects in gallium nitride as it is manufactured; the team also built computer models to design devices that work well despite such defects. The result: gallium nitride devices that provide about seven times the power of other semiconductors at certain microwave-communications frequencies. GE is collaborating with Lockheed Martin to deliver high-power radar for lightweight, unmanned military aircraft in five to ten years.

SMART SUIT

Imagine a wet suit that goes on loose, then snugs down to keep you warm as you descend to icy depths. Thanks to smart-materials developer Midé Technology of Medford, MA, such suits are on the way. To make the suits work, Midé spikes neoprene, the standard wet suit material, with isopropylacrylamide, a "hydrogel" material that swells when it is warmed and contracts as it cools. Midé president Marthinus van Schoor says the hydrogel-neoprene suit, developed for the U.S. Navy Seals, hugs the diver in cold seas, reducing the amount any water trapped inside the suit sloshes across the skin and carries away heat; in tests at 13 °C, hydrogel-impregnated suits provided 70 percent more thermal protection than neoprene alone. Santa Cruz, CA-based wet suit manufacturer O'Neill plans to test the Midé technology. If it passes muster, divers won't be left shivering for much longer.

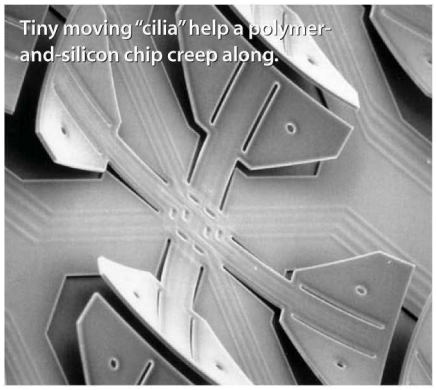
BACTERIA PUMP

As microscale devices get smaller and smaller, researchers look for new ways to control movements inside them. A team at the University of Arkansas, led by mechanical engineer Steve Tung and bioengineer Jin-Woo Kim, has developed a way to pump tiny amounts of fluid by harnessing the motions of living cells. Unlike electrical or mechanical systems that rely on high voltages or pressures, the new technique uses harmless bacteria, each of which attaches a leglike appendage to a flat surface and rotates about this anchor point. The rod-shaped bacteria spin "like a merry-go-round," says Tung, at 10 cycles per second. The trick, he says, is getting the cells to stop, go, or change speed by adjusting their glucose intake. With a few cells lined up in a glass-walled channel, Tung and Kim plan to show that the device can move the 0.25 nanoliters per minute a computer model predicts is possible. Tung says that could lead to biomechanical chips for drug delivery and DNA sequencing in about three years.



Spinning bacteria like these could pump fluids through drug delivery tools and other devices.

COURTESY OF JIN-WOO KIM (BACTERIA); COURTESY OF GENERAL ELECTRIC (MINIMICROWAVE); COURTESY OF MXISYSTEMS (RADIOGRAPH)



Tiny moving "cilia" help a polymer-and-silicon chip creep along.

CREEPY CHIPS

Polymer-and-silicon chips lined with tiny structures that act like biological cilia, or hair cells, could provide a new way to position and assemble delicate hardware, says electrical engineer Karl Böhringer at the University of Washington. Activated by heat, the artificial cilia work in groups of four, each group measuring about one millimeter across. Each chip has 256 cilia: Flip the chip upside down, and it can walk on a table. Put a platoon of them on the outside of a space station, and they could grab hold of a small satellite and make minute adjustments to its position as it docks, refuels, and transfers data. In collaboration with Stanford University, Böhringer has shown that an array of four chips can align a mock satellite the size of a tennis ball by nudging it to and fro. But the researchers will need to reduce power consumption by a factor of 10, he says, before the chips will be ready for space. A possible solution: electrostatically activated cilia, which are in development and could be ready for testing within a year.

NO-TROUBLE TRANSPLANTS

A simple procedure could make life-saving bone-marrow transplants much easier on patients and increase the number of potential donors. Developed by cancer immunologist Ellen Vitetta and her colleagues at the University of Texas Southwestern Medical Center in Dallas, the process could dramatically lower the risk of a complication known as graft-versus-host disease, in which blood cells made by the donor marrow attack the recipient's tissues. Vitetta's solution: eliminate the donor cells that cause the complication and spare those that fight disease. Prior to transplant, doctors mix the donor marrow with the recipient's blood to activate the "bad" cells. Once activated, these cells display a molecular marker called CD25 on their surfaces. Vitetta then adds a toxin attached to an antibody that targets CD25; the hybrid molecule selectively kills the bad marrow cells, and the rest are then infused into the patient. In an early trial in France, the procedure reduced the incidence of graft-versus-host disease from 70 percent of transplants to 25 percent. Vitetta hopes to begin U.S. clinical trials this spring.



This gravel-size "pebble" wirelessly reports on a bridge's health.

SMART PEBBLES

Monitoring the health of bridges requires either drilling out a core sample or embedding boxy sensors that monitor for the intrusion of rust-inducing salt. The first method is labor-intensive; the second relies on wires that can break or degrade. Researchers at SRI International in Menlo Park, CA, are developing an alternative they call a smart pebble. The wireless device, the size of a piece of gravel, can be poured right along with the concrete. The SRI team built the pebble by linking a new type of chloride sensor to an off-the-shelf wireless-communications chip and tucking both into a housing made of cementlike materials. The sensor develops a voltage whose strength is determined by salt concentration. To collect the sensors' readings, a device mounted on the underside of a van could emit a blast of radio energy as the vehicle drives over a bridge. Each radio query identifies an individual pebble; the code number that bounces back indicates whether salt levels are above or below a certain threshold. SRI is preparing prototype pebbles for the California Department of Transportation, which plans to test them this year.

WONDER WINCH

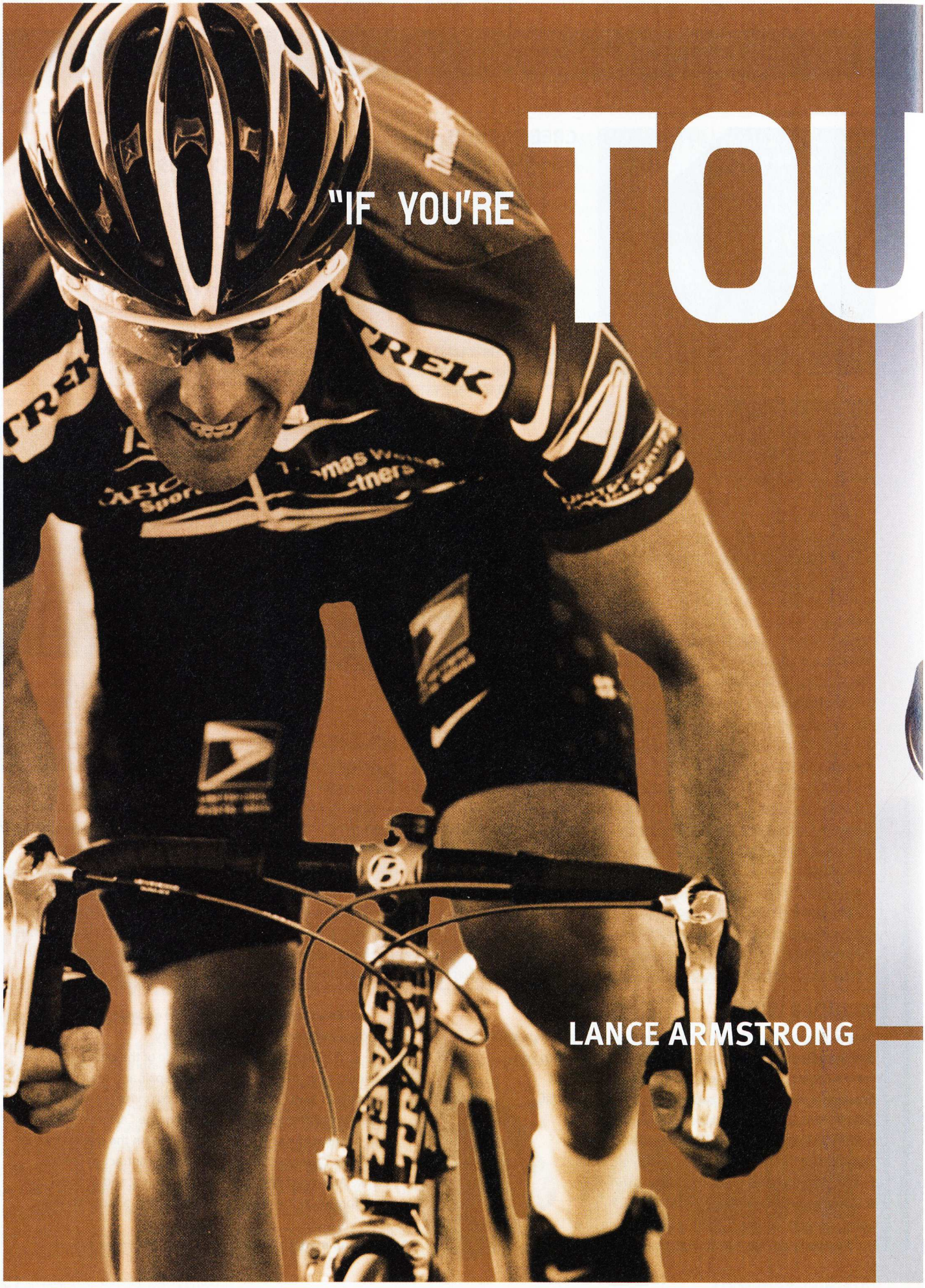
Able to leap tall buildings in a single bound? Not quite. But a new tool from Quoin International in Ridgecrest, CA, will help you scale a five-story building in about 15 seconds without breaking a sweat. Attach a cable to the top of a wall, cliff, or utility pole, and the portable, two-kilogram winch pulls you up. The key to powering the device, says Quoin CEO Mike Jacobson, is a carefully controlled piston that generates gas at four times the pressure of a conventional turbine compressor. This novel compressor drives a high-speed turbine that produces enough force to lift 100 kilograms steadily. And unlike a conventional turbine, the engine can start and stop frequently without losing efficiency.

The winch could take the place of the pulleys and scaffolding now used in construction, repair, and search-and-rescue operations, says Cathy Jacobson, Quoin's vice president of business development. With support from the California Department of Commerce, she says, a trial unit will be on the market by summer. Quoin developed the system under contract to the U.S. Defense Advanced Research Projects Agency, and a model optimized for use by the military will be ready in about two years.



A two-kilogram winch could make scaling buildings a breeze.

COURTESY OF QUOIN INTERNATIONAL (WONDER WINCH); COURTESY OF SRI INTERNATIONAL (SMART PEBBLES); COURTESY OF JOHN SUH (CREEPY CHIPS)


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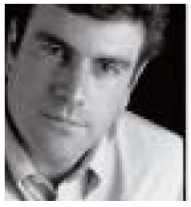
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GLOBAL WARNING

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Global innovators are challenged by an intensifying commercial challenge not only to create new products, but also to justify the processes they employ to produce those products. Colorful cosmetics that make us prettier are wonderful; cruelly testing them on animals is not. Creative fashions made of affordable new textiles are terrific; ruthlessly exploiting third-world child labor to produce them is not. Herbicide-free grains and vitamin-enriched vegetables are healthy innovations; unless, of course, they're the wicked Frankenfood monstrosities of recombinant DNA.

Processes, not products, have become the prime targets of activists, regulators, and litigators who recognize that the most cost-effective way to disrupt the introduction of a new kind of technology is to shatter the vital links of its supply chain. Global innovations no longer compete purely on features, functionality, and price; they compete on the global processes that create them. Because the manufacture of novel products can require novel processes, the most innovative companies prove particularly vulnerable to the most inventive activists.



That means successful innovators had better be clever and comprehensive about their marketing of both *how* they innovate and *what* they innovate. The tale of genetically modified foods in Europe, the United States, and Africa offers a perfect case study in the pitfalls of process-marketing mismanagement.

Bitter disagreements over genetic modification on both sides of the pond make intercontinental disputes concerning the United Nations and the environment look tame. Europeans have been consistently hostile to the introduction of genetic engineering into the food chain. They say genetically modified foods are innovations that represent the unknown, the untested, the unsafe, and the inherently unnatural. A coterie of French chefs has organized public boycotts of genetically engineered foods in their restaurants, and these chefs have encouraged other fine dining establishments across the continent to follow suit. Indeed, activist Europeans have had an effect. Several African countries have refused genetically modified seeds and foods from the United States, despite chronic food shortages that threaten the health of their people. The coordinated opposition to such processes and products is as global as any multinational corporation.

By consistently lobbing clumsy responses to public criticism, such genetic-engineering pioneers as Monsanto have been the nascent technology's own worst enemies. These companies have placed themselves in the awkward position of arguing that their new processes don't fundamentally change the products—as if manipulating the molecules of a tomato to extend its "freshness" doesn't *really* change the fruit. A large part of the industrialized world—literally and figuratively—isn't buying it.

Indeed, the purveyors of genetically modified foods have been so thoroughly demonized that they now seek regulatory protection worldwide, and they are fighting all efforts that would force their customers to disclose whether they use any genetic engineering in their products. In other words, what might have been seen as a "feature" in an altered tomato is being regarded as a "bug." Opponents of modified foods dismiss the notion that genetic engineering might allow for foods that are less expensive, more robust *and* every bit as safe and nourishing as so-called natural products.

No simple or obvious market solution exists for the innovators of genetically modified food or for any company looking to tread new ground in any industry. Much like companies that are obligated to comply with international process standards to signal their investment in quality, innovators are also being challenged to more fully disclose their compliance. A software company might produce better, faster, and cheaper products by outsourcing its development to Russia, and that's information many key customers may want to know. The Pentagon, for example, might look askance at certain security subsystems' being coded and tested in St. Petersburg. Perhaps public school systems will be precluded from acquiring PCs whose motherboards were produced by underage laborers in Malaysia. Soccer moms may want to avoid purchasing cosmetics that were tested on animals.

The dark underbelly of the processes that generate a brilliant innovation may subvert its success in the marketplace. The coordinated opposition is as global as any multinational corporation.

To the extent that human rights, economic development, and public safety issues might become purchasing criteria of early adopters, innovators will have to focus both time and care on assuring critical consumers that the integrity of the processes match the value propositions of the technical developments. Innovators now need "process" marketers to complement their "product" marketers. The dark underbelly of the processes that generate a brilliant innovation may ultimately subvert its success in the future marketplace.

For companies that aspire to global reach, branding their processes will matter as much as branding their products. Treating supply chains as separate and distinct from the products they create will be impossible. Innovators beware. TR

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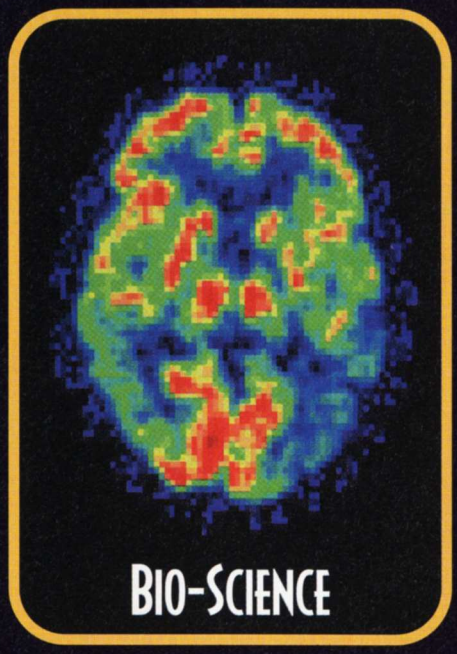
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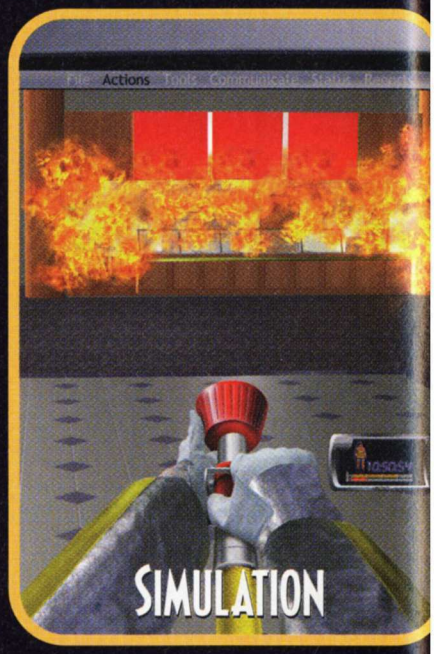
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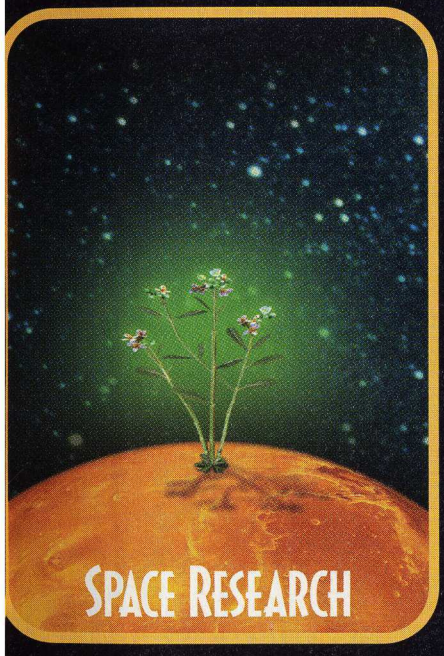
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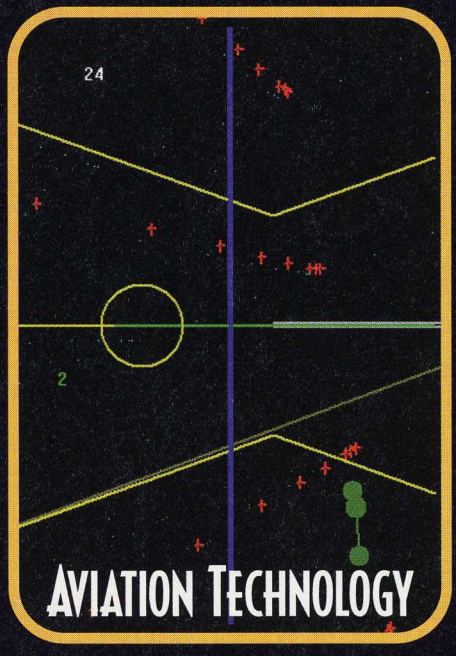
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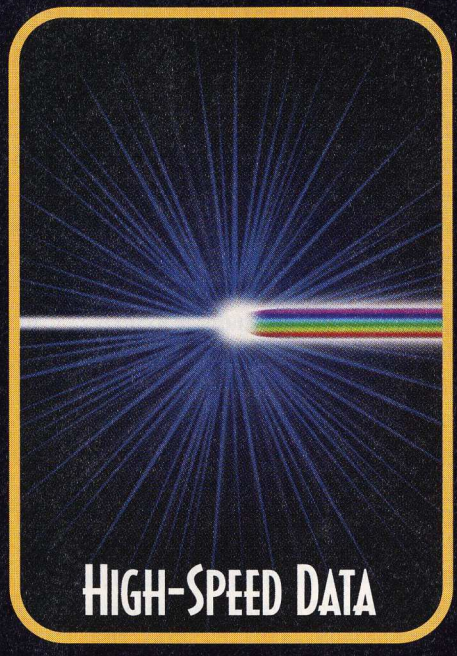
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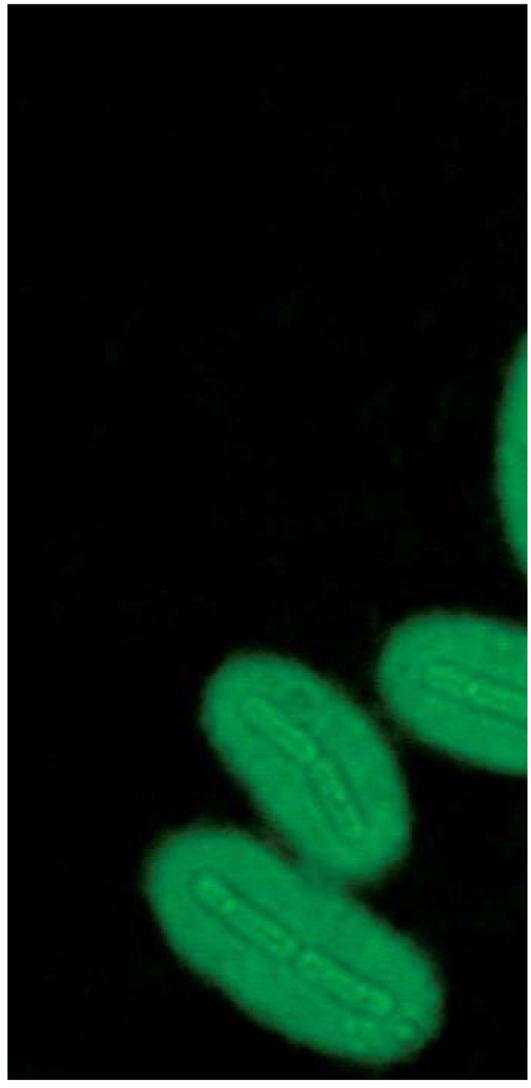
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ATTACKING ANTHRAX

Promising new antibiotics, antidotes, and vaccines emerge



Anthrax stands apart in the rogue's gallery of bioterror diseases: the bacterial spores that cause it are relatively easy to acquire, mass-produce, and disseminate. They are extraordinarily lethal when inhaled, and antibiotic-resistant strains are easy to make. Moreover, as the five mail-attack deaths grimly demonstrated in 2001, modern medicine is powerless against late-stage anthrax, in which bacterial toxins cause deadly blood poisoning and organ damage.

"Biological weapons are the biggest national security threat facing the nation," says Tara O'Toole, director of the Center for Civilian Biodefense Strategies at Johns Hopkins University. Anthrax, she adds, is "a much more serious threat than smallpox. I think it's much easier to imagine terrorists getting hold of the bug, the technology, and disseminating anthrax than doing all this with smallpox."

But against these realities, significant progress is afoot. A host of rapidly emerging approaches promises to save lives in future anthrax attacks, whether on the battlefield or on the home front. New treatments that kill the bacterium—*Bacillus anthracis*—and deactivate the deadly toxins it produces should become available within the next year or two. And better vaccines are on the way to replace the 18-month-long vaccination regimen that is already standard for hundreds of thousands of military personnel.

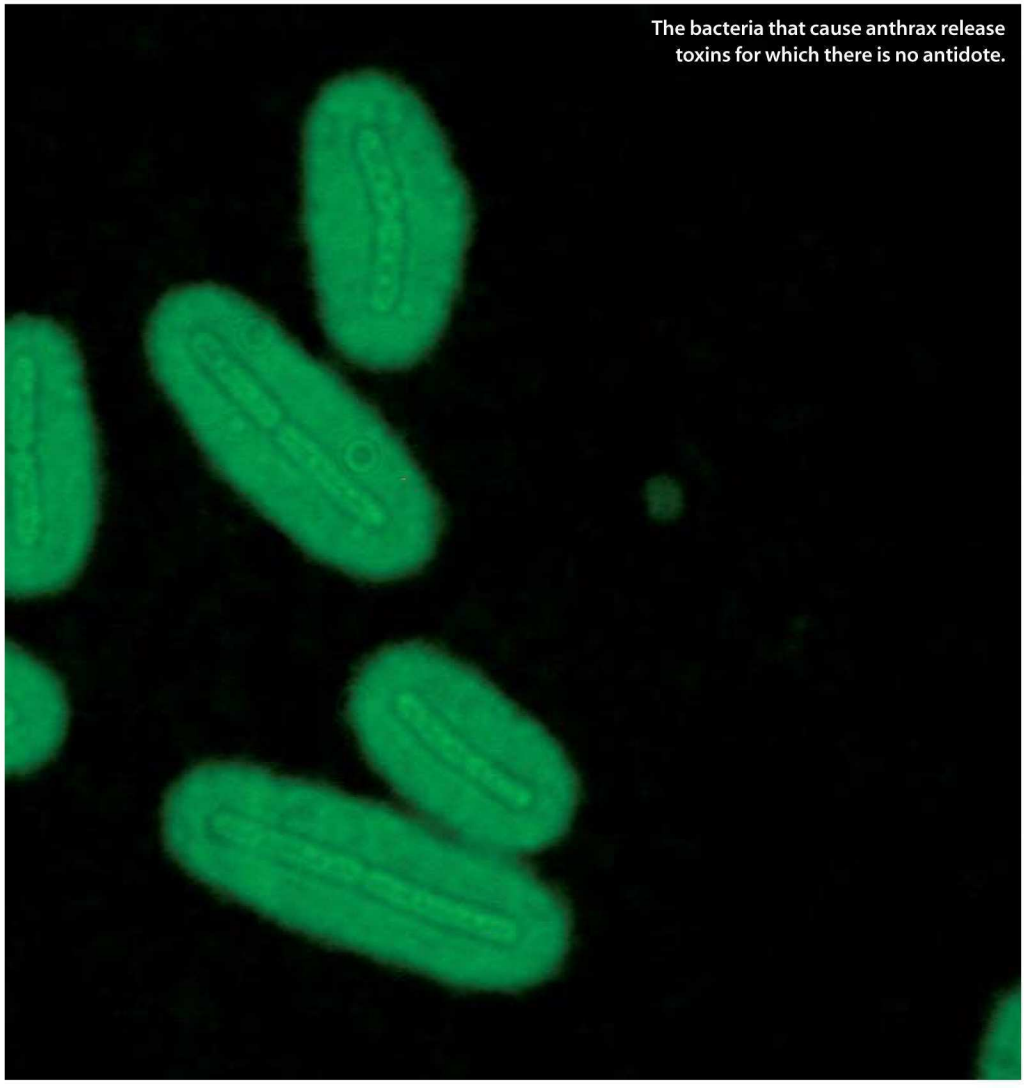
The first mission: combating antibiotic resistance. Anacor Pharmaceuticals in Palo Alto, CA, is developing a new class of antibiotics that block an enzyme certain bacteria—including *Bacillus anthracis*—need to replicate their DNA. Although the difference between this approach and the way some existing antibiotics work is subtle, it is significant enough to "increase the difficulty [for terrorists] by an order of magnitude," says Anacor CEO David Perry. That's because each new line of antibiotic attack makes it less likely that the bugs will have evolved the means to escape or that rogue states or terrorists will have engineered the right type of resistance, he says. Anacor, which last year won a $21.6 million grant from the U.S. Department of Defense to develop new compounds, has already started animal tests and expects to have drugs in human trials within three years.

Another antibiotic approach pits a virus against anthrax. Rockefeller University microbiologist Vincent Fischetti identified an enzyme from a virus that infects only anthrax-causing and closely related bacteria. In test-tube experiments, the enzyme kills about a hundred million bacteria in two minutes or less. "It drills a hole in the cell wall, and the organisms explode," Fischetti says. He adds that the treatment should boost the power of existing antibiotics against anthrax, as well as kill resistant strains of the bacteria. His group is currently performing animal experiments to test the enzyme further.

Such superantibiotics could play a critical role should an anthrax attack use an antibiotic-resistant strain. But what's needed most urgently is a treatment to counteract the potent toxins produced by *Bacillus anthracis*. These toxins attack the cells of those infected; in fact, researchers believe they are what killed the five anthrax victims in 2001, despite the patients' treatment with powerful antibiotics. Experimental anthrax infections in monkeys show that "there comes a point of no return," says Michael Mourez, who, as a postdoc in biochemist R. John Collier's lab at Harvard Medical School, studied anthrax toxin. "You can treat the animal and get rid of the bacteria, and yet the disease will progress towards death."

Collier's group has developed several molecules that effectively protect animals against the toxins. Rats typically die within 90 minutes of being injected with anthrax toxin. If the rodents are given one of these antidotes, however, they survive. Even before the 2001 attacks, Collier had formed PharmAthene, a Potomac, MD-based company, to develop one such antidote into a drug. The treatment the company is testing is a mutant version of one of the proteins that make up the toxin; it binds to the other components to prevent the formation of active toxin. This protein could act as both a vaccine and a drug. If testing goes well, Collier anticipates that the treatment may be available in limited quantities next year.

That's an optimistic timetable: drug development typically takes 10 years. But Collier may well meet his goal because last year the U.S. Food and Drug Administration moved to speed approval of treatments that improve the nation's readiness to respond to bioterrorism.



The bacteria that cause anthrax release toxins for which there is no antidote.

COURTESY OF M. DRYSDALE AND T. KOEHLER, UNIVERSITY OF TEXAS MEDICAL SCHOOL AT HOUSTON

Modern medicine is powerless against the late stages of anthrax. But urgent research efforts are yielding new ways to kill the bacterium and neutralize its deadly toxins.

Rather than undergoing the usual extensive preclinical animal testing and three-phase human trials to establish drug safety and efficacy, treatments such as Anacor's, Fischetti's, and PharmAthene's will have only to demonstrate effectiveness in two different animal models and safety in one human trial.

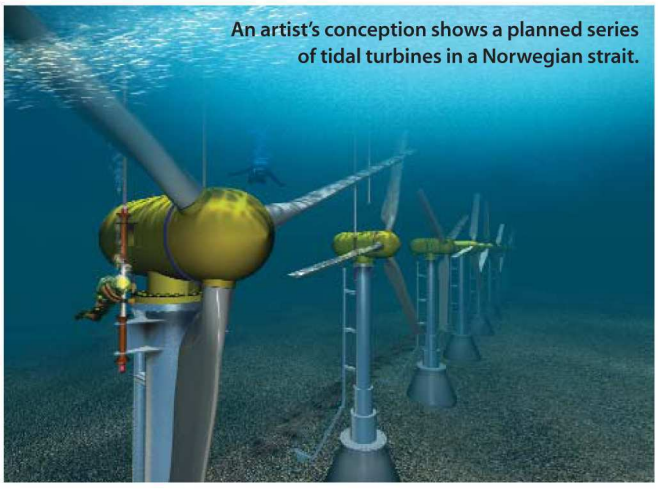
Improved vaccines are also critical. Current anthrax vaccines are safe and effective, but for full protection, recipients require six doses over 18 months, a delay that could be costly for military troops who will be the main beneficiaries of any new vaccines. But fast-acting vaccines could also allow civilians to live or work in contaminated areas after an attack. The anthrax spore is difficult to destroy: even now, the Washington, DC, postal facility that handled two contaminated letters in 2001 remains shut down.

In an effort to reduce both the number of doses and the time needed to protect people from anthrax, researchers at Frederick, MD-based DynPort Vaccine and Avant Immunotherapeutics in Needham, MA, have developed a vaccine they hope will induce protective antibodies more quickly. The current vaccine is basically a "soup" of bacterial cell parts; the new vaccine comprises only protective antigen, the same toxin subunit on which Collier's treatment is based. This specificity should help avoid side effects while speeding the body's immune response. Clinical trials started in October 2002.

Avant plans to go even further. It recently received a government subcontract to create a single-dose oral vaccine that will shield against both anthrax and plague, a flea-borne bacterial disease that could also be a bioweapon. Contracted through DynPort from the Defense Department's Joint Vaccine Acquisition Program, the project's costs may exceed $8 million over two years. "This isn't just a research idea," says Una S. Ryan, Avant's president and CEO. "It's pretty well down the development line."

To start making this vaccine, Avant's scientists have removed disease-causing genes from cholera and salmonella bacteria. They plan to insert genes that code for proteins made by anthrax- and plague-causing bacteria. The resulting proteins should prompt the body to produce disease-fighting antibodies. "You'll get protection against cholera, anthrax, and plague with one swig-and-go," says Ryan. Avant's plans call for beginning human tests of this vaccine within two years, she adds.

Indeed, more effective vaccines and treatments for anthrax won't be the only payoffs from the current surge of bioterror defense research. Anacor's new antibiotics, for example, should work not only against anthrax and other bioweapons, but also against such common diseases as pneumonia and bacterial meningitis and staph infections. "All this money is not only going to be useful for biowarfare organisms," Fischetti says. "It's going to be a real shot in the arm for how we deal with infectious diseases." But even without such medical windfalls, these new treatments for anthrax will help build much-needed defenses against this major bioterror threat. —*Erika Jonietz*



An artist's conception shows a planned series of tidal turbines in a Norwegian strait.

TAPPING THE TIDES

First "underwater windmill" hitting the grid

ENERGY | A handful of tidal-power plants dot the world, and most of them are sprawling facilities that impound incoming water in estuaries, block shipping, and disrupt marine life. But 50 meters under the sea, at the bottom of a remote Norwegian strait, the world's first unobtrusive, grid-connected "watermill" will soon produce power for the world's northernmost town.

It looks like a wind turbine, except it's anchored to the seabed. Tidal currents moving at 2.5 meters per second spin three 10-meter fiberglass blades, generating power that is sent to the grid via a cable. When the tide turns, the blades twist 180 degrees, reversing the direction of the watermill's rotation. Electricity from the 200-ton apparatus is expected to hit the grid this spring, providing enough power for between 40 and 50 houses. "This is the first mill-type system hooked up to the grid," says Anthony Jones, a San Francisco-based ocean-energy consultant. "I'm betting that they'll be quite successful."

That's partly because Hammerfest Strom, the company behind the project, tapped ocean-engineering expertise from partners that include Zurich, Switzerland-based ABB and Statoil in Stavanger, Norway. Project leader Bjorn Bekken says a modular design allows replacement of broken parts, while redundant hydraulics and control systems should minimize service calls. Eventually, repairs will be performed by remotely operated vehicles similar to those used on offshore oil platforms.

The prototype is the first and smallest of 20 mills slated for the Kvalsund Strait—near the town of Hammerfest, 1,360 kilometers north of Oslo. They will supply enough power for 800 to 1,000 houses within a few years. Although it is twice as costly as wind power right now, "the watermill has just started its development, and I think it will be competitive with the windmill within 10 years," says Ole G. Dahlhaug, an engineer at the Norwegian University of Science and Technology in Trondheim, Norway.

Hammerfest Strom isn't the only company aiming to build watermills. Hampshire, England-based Marine Current Turbine plans to install a prototype watermill just beneath the waves off the coast of Lynmouth, England, by early summer. Together, these efforts could turn the tide for this renewable power source. —*Steve Mollman*

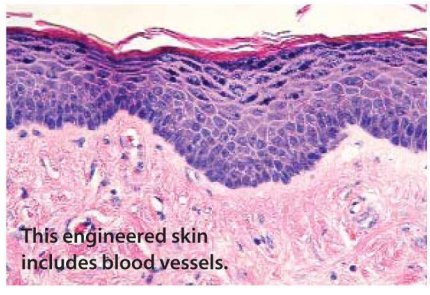
NEW VEIN FOR SKIN GRAFTS

BIOTECH | Replacement skin could save the lives of severely burned patients and spare them from painful skin-graft-harvesting operations. But today's "artificial skin" products are used only as temporary dressings for wounds, not permanent grafts for burns, in part because they're made without something vital to the survival of skin grafts—blood vessels. A handful of researchers are working to change that.

One method combines several types of cells with genetic engineering. Yale University dermatologist Jeffrey Schechner starts with dermis—the skin's bottom layer—from organ donors. He strips cells from this tissue and adds keratinocytes—the cells that make up the top layer of skin—from the foreskins of circumcised baby boys. Next he adds endothelial cells that come from the lining of veins in umbilical cords and have been genetically engineered to produce a growth-promoting protein. These cells multiply and line the channels left by the dermis's original blood vessels.

All this may sound a bit ghastly, but it seems to work as Schechner described last spring at the annual meeting of the Society for Investigative Dermatology. Schechner grafted the new skin onto the back of a mouse, and two weeks later he found red blood cells in the channels of the graft—an indication that the mouse's blood vessels had linked with the synthetic ones. Schechner is now fine-tuning his system.

One issue: how to ensure that a graft doesn't trigger an immune reaction. "Endothelial cells are extremely immunogenic—they're one of the main targets of rejection in organ transplantation," says François Auger, director of the Laboratory of Experimental Tissue Engineering at Canada's Laval University. Researchers at Laval and at Shriners Burns Hospital in Cincinnati plan to use patients' own cells,



This engineered skin includes blood vessels.

multiplied in the lab, to grow skin. The Shriners team seeds the cells on a fabric-like collagen scaffold. The Laval group coaxes the cells to secrete the proteins necessary to build their own scaffolding.

It will be at least a year before any of these new skins is ready for human testing. But given that burns each year hospitalize 45,000 people in the United States and kill hundreds of thousands worldwide, successful approaches could mean less pain and save more lives. —*Rebecca Zacks*

COURTESY OF JEFFREY SCHECHNER (SKIN); COURTESY OF TORGEIR AUNE (TIDES)



A MORE ANONYMOUS INTERNET

ENCRYPTION | Identity theft and credit card fraud are surging international problems, fueled partly by the need to reveal credit card and Social Security numbers in the course of common Internet transactions. Although most businesses immediately encrypt such numbers, researchers at IBM's Zurich Research Laboratory and elsewhere are devising ways to avoid having to submit the numbers in the first place.

IBM calls its solution Idemix. The software could, for example, allow you to prove to online merchants that you have a valid credit card with certain spending limits, without actually entering the card number. The software starts by enabling you to get an anonymous digital credential from the bank that issued your credit card. This credential contains a pseudonym you choose, the credit card number and its expiration date, and encoded data from the bank that helps verify the credential later.

Then, let's say you want to buy a Kenny G. disc online. The Idemix software in your PC sends information encrypted in the credential to the online music store, informing it that you have a valid credit card. At the store's payment center, another part of the Idemix software reads that information. It uses cryptographic algorithms to confirm bank authorizations and spending limits and to collect payment—all without knowing your actual card number. "This set of techniques is really out in front," says Ronald Rivest, a computer scientist at MIT and a coinventor of a widely used encryption algorithm. Idemix changes the encrypted version of your credential each time you use it, making it harder for Web sites to track your habits.

Just as banks could issue anonymous credentials, so too could government agencies that issue driver's licenses, Social Security numbers, and other forms of identification. Consider car rentals: an anonymous credential could allow you to prove you are a licensed driver without your having to hand over your actual license. IBM already has prototypes running and could have a version ready for market in one to two years, says Jan Camenisch, lead cryptographer of the Idemix project in Zurich.

Of course, IBM isn't the only company trying to provide secure e-commerce. Credentica of Montreal, Quebec, is also working to commercialize digital credentials for broader applications. And many academic and corporate research groups are pursuing strategies for more anonymity on the Internet. There's good reason for all this research: last year, according to the Federal Trade Commission, 162,000 identities were stolen in the United States alone, and Internet fraud cost consumers more than $122 million. And someone out there knows you love Kenny G. —*Tracy Staedter*

SPACE REPAIRMAN

ROBOTICS | Although the events that doomed the space shuttle Columbia may never be fully understood, investigators have focused on damage to thermal tiles inaccessible to the astronauts. In the future, says Robert Ambrose at NASA's Johnson Space Center in Houston, crews on the International Space Station or a shuttle might include a robotic repairman.

NASA's "Robonaut" is getting close to realizing that vision. With its human-size palm, four fingers, and an opposable thumb, Robonaut is "phenomenally dexterous," says Alan Peters, a researcher at Vanderbilt University's Center for Intelligent Systems. "It has the best hands of any robot on the planet." This allows Robonaut to use wrenches and other hand tools.

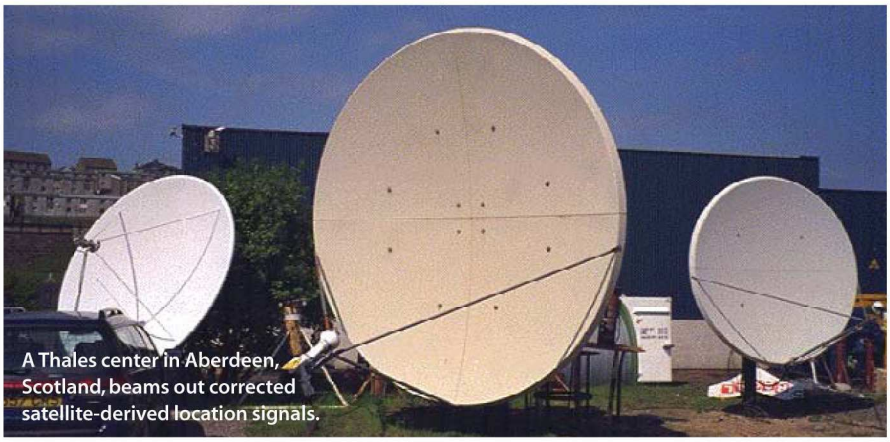
Currently, sensors on a human operator's body translate the operator's movements into the robot's actions. The human sees what Robonaut "sees," thanks to cameras mounted in the robot's head. But mechanical engineer Marcia O'Malley at Rice University is developing a sleeve containing tactile vibrators that will enable the operator also to feel what the robot "feels." The payoff: more accurate control.

This tactile dimension might also let Robonaut learn what jobs should feel like, Ambrose says. This could help the robot become fully autonomous, a goal of research collaborators at the University of Southern California. Robonaut could be headed for space in three years.
—*Gregory T. Huang*



Robonaut grips mock spacecraft handrails.

COURTESY OF AUTOMATION, ROBOTICS, AND SIMULATION DIVISION AT NASA (ROBONAUT); JAMES YANG (ILLUSTRATION)


A Thales center in Aberdeen, Scotland, beams out corrected satellite-derived location signals.

FIXING THE LOCATION FIX

Ten-centimeter GPS resolution is quite close to being here

SOFTWARE | Hikers and drivers who use satellite-derived location information may not need to know their latitude and longitude down to the decimeter. But phone company workers digging near fiber-optic cables, drillers working on offshore oil-and-gas rigs, and farmers tracking crops row by row do need that kind of accuracy. Right now, though, they depend on expensive, localized ground-based reference-and-correction systems to get high precision from the 24 satellites of the Global Positioning System (GPS), run by the U.S. Department of Defense.

That's about to change. Thales, the French aerospace giant, says it has developed the first GPS-correction service that's accurate to within 10 centimeters virtually everywhere on the planet—compared to the one-meter precision guaranteed by similar existing services. "This makes something that was once very difficult much easier, because you won't need expensive equipment," says Andrew Barrows, president and founder of Nav3D, a Palo Alto, CA-based company that develops graphical location displays. The Thales system will beam out signals that subscribers can use to continuously clean up coordinates on ordinary GPS receivers. "They are saying, 'throw out all your GPS-correction infrastructure; we'll just send you the signal,'" Barrows says.

A GPS receiver fixes location on the basis of the travel time of radio signals from at least three of the 24 GPS satellites. The Thales system is a "new milestone" in sophisticated computer algorithms that attack several sources of error in the satellite coordinates, says Angus Cooper, marketing director for Thales GeoSolutions Group. By independently tracking satellites' locations, Thales double-checks the coordinates reported by the satellites. Then it corrects for atmospheric disturbances that might alter signals' travel time and for known errors within the clocks aboard each satellite. Finally, the company maintains 85 ground-based reference stations worldwide. The correct coordinates of these fixed stations are known, and they are continually compared against the coordinates reported by GPS. By this summer, Thales expects to beam ultracorrected GPS signals from outposts in Singapore and Aberdeen, Scotland, to paying customers.

The system will help farmers spread seed and fertilizer only where needed and even track individual plants for research. The technology should be a special boon for offshore oil-and-gas drilling industries, which need precise information to map their work locations and can't install fixed-reference stations at sea. And it could help utilities map existing rights of way and workers dig without disturbing buried cables.—*David Talbot*

MACHINING MELODIES

ARTIFICIAL INTELLIGENCE | **The marriage of computers and music has spawned digital instruments that sound "real," an interface—the musical-instrument digital interface—that's now an industry mainstay, and composition software that helps generate ideas, assemble phrases, and analyze existing works.**

But now machines are actually learning to compose music of their own. Eduardo Miranda at England's University of Plymouth has developed software that generates music from scratch. Other composition software tools rely on high-level mathematical rules, but Miranda's approach is "bottom-up," he says. His software, which grew out of his research at the Sony Computer Science Lab in Paris, France, adapts ideas from the field of artificial intelligence to create a sort of virtual orchestra. Ten "players" get together and generate simple sequences of musical notes. Each player is programmed to listen, evaluate, imitate, and generate variations. After running for a few days, the artificial society produces haunting melodic streams.



These melodies are still ploddingly crude. "This is a beginning to getting a computer to create something new," Miranda says. The next step, he adds, is to evolve rhythms and dynamics.

It's too soon to say whether creative machines will supplant their flesh-and-blood counterparts, but "the technology is here," says Rodney Waschka II, a North Carolina State University researcher. Initially, such technology will help human composers by speeding the process and providing new ideas. In the long run, boy bands beware. —*Gregory T. Huang*

JAMES YANG (ILLUSTRATION); COURTESY OF THALES (FIXING THE LOCATION)



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SIMSON GARFINKEL

PROOF OF CONCEPT

In the military, most new weapons systems go through an evaluation, or proof-of-concept, phase. These are not full-power tests, but baby steps to show that key technology should work as advertised.

This sort of testing takes place not only with missiles and bombs but also with the cybernetic implements of information warfare. Indeed, any group that is developing tools to disrupt an adversary's information systems would be downright irresponsible if it did not conduct proof-of-concept demonstrations as part of its R&D process. These tests would not cause great harm: instead, they would be designed to whet the appetite of officials higher up the command chain.

And what would a proof-of-concept demonstration for an information warfare weapon look like? Possibly a lot like the computer virus attacks the Internet has experienced in recent years. I suspect that some of these electronic attacks were actually the results of deliberate tests for a future attack that could have truly dire consequences.



To understand my alarm, you need to understand the anatomy of computer viruses and their cousins, worms. Most of these hostile programs have three parts. The first, the "exploit," is the technique the virus or worm uses to break into systems. Most exploits take advantage of a known security flaw—for example, the classic "buffer overflow," in which an excess of incoming data corrupts the information already stored in memory. The second part, the "propagation engine," is the code that targets computers for attack. And the third, the "payload," does the actual damage.

Viewed through this morphology, the major worms that have disabled computers on the Internet—Code Red, Nimda, Klez, and, most recently, Slammer—share a disturbing similarity. Each one employed a novel—and extremely effective—propagation engine. But for exploits, all these worms have used security vulnerabilities that had been previously identified. And as for the payload: all were duds. Even though each gained so-called administrative privileges to alter the systems they infected, none used its privileges to cause mayhem.

Sure, they did some harm. But in nearly every case, the damage was caused by the propagation itself—as if a burglar systematically were to break windows, enter every house on the block, and steal nothing. An actual payload could scramble financial data, erase operating systems, and ruin motherboards by wiping out the contents of their programmable chips.

This pattern has been repeated so many times that I believe at least some of these worms are in fact elaborate proof-of-concept tests, created by a clandestine information-warfare lab. This is more plausible than you might first think. Many of the computer viruses written over the past 20 years have been the work of a small group of teenagers and young adults engaged in competition with their friends and various antivirus companies. The virus creators quickly learned that any bozo could write a program that could erase other people's hard drives. By the mid-1990s the rogue programmers had elevated the game: scoring points among fellow hackers required clever propagation techniques and tricks for outrunning the antivirus shops. Law enforcement agencies know that hackers from the 1990s are now selling their services to organized crime and terrorists; why not the virus writers?

Remember: not a single worm or virus that we have seen in the wild—not one—has employed a novel exploit. That's not surprising. Unknown exploits are far too valuable to reveal in public proof-of-concept testing. Likewise, no worm has deployed a payload that caused significant damage. Why set the death ray to kill, when all you are trying to do is prove that the thing shoots?

Fred Cohen, a computer security researcher who has been studying malicious programs for two decades (and who is credited with coining the term virus), doubts that the worms we have seen are the work of government-run information-warfare labs. But he concedes that smaller labs or solo operators—possibly renegade operations in China or independent outfits looking to sell their services—might have released weakened versions of their worms into the wild as tests. The U.S. military set a sort of precedent in the 1960s when it tested "simulant" germ-warfare agents in the New York City subway and off the coast of San Francisco. And it is widely believed that the original Microsoft Word macro virus, auspiciously named Concept, was written as a proof-of-concept test by a programmer at Microsoft and was inadvertently released on discs at a developers' conference.

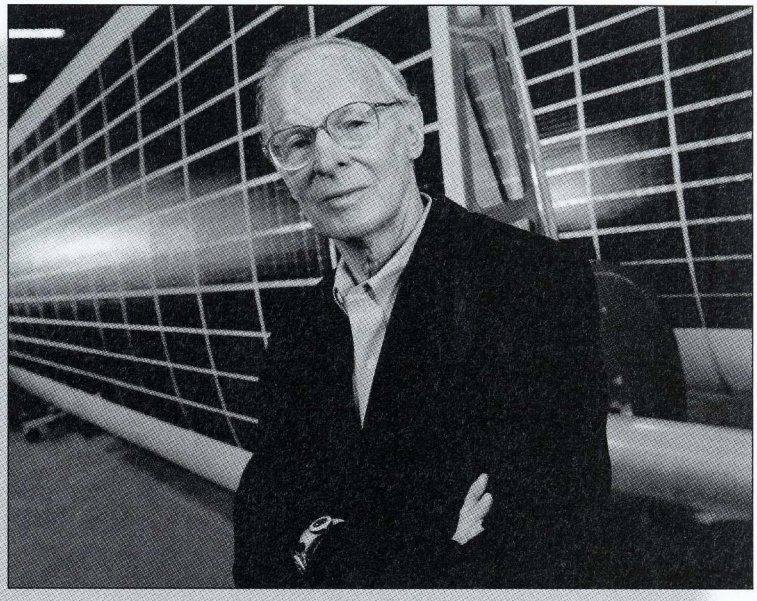
No computer virus or worm that has been released on the Internet has deployed a truly damaging payload: why set the death ray to kill, when all you are trying to do is prove that the thing shoots?

Speculation about the origin of these worms has taken on more relevance since last summer, when President Bush reportedly signed an order directing the U.S. government to develop guidelines for launching a cyberattack against enemy computer networks. Before that order, my friends in the military were saying that the United States would never consider conducting an offensive information-warfare campaign: as the nation with the most computers, we have the most to lose. But now our government is in the process of legitimizing cybernetic warfare.

I'm worried. Today's lame computer worms, even with well-known exploits and dummy payloads, have shut down corporate and government networks. A determined enemy would target a new exploit with a really nasty payload. The proof that time could be a hundred billion dollars in damage. TR

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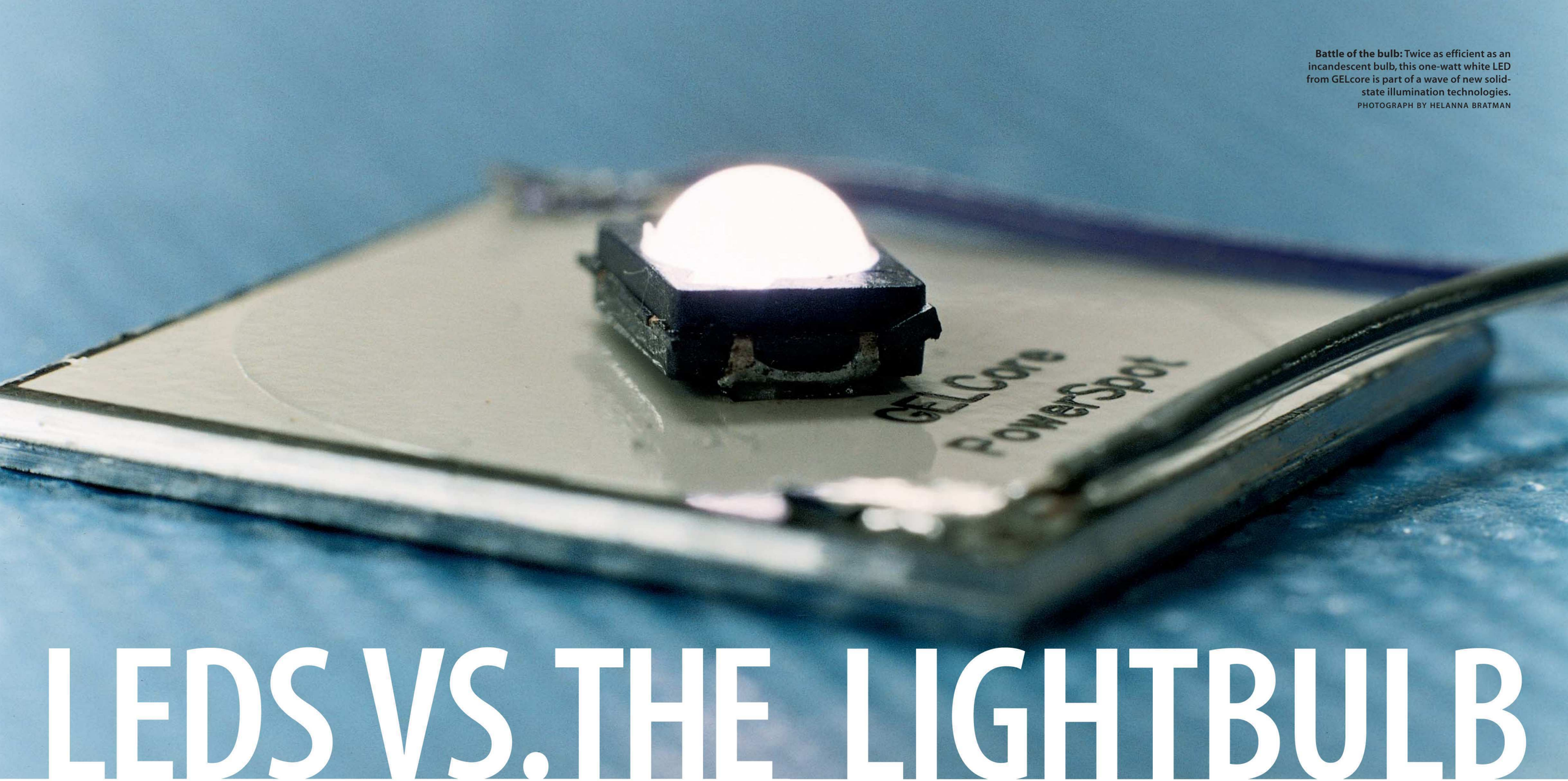
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Battle of the bulb: Twice as efficient as an incandescent bulb, this one-watt white LED from GELcore is part of a wave of new solid-state illumination technologies.
PHOTOGRAPH BY HELANNA BRATMAN

LEDS VS. THE LIGHTBULB

Roll over, Thomas Edison: LIGHT-EMITTING CHIPS are poised to usher in a new era of illumination. **BY DAVID TALBOT**

IT'S A SUNNY DAY ON THE CAMPUS OF the University of California, Santa Barbara, but little light penetrates the labs and offices of Shuji Nakamura. Shades sheathe the windows in part because, Nakamura says, "I worry about unknown people around here—that they will include a spy."

That sounds farfetched until you consider that Nakamura, who played a lead role in the development of blue light-emitting materials, is now back for a second act. In the 1990s Nakamura gained fame by cooking up the first semiconductor materials to emit bright blue light—a boon for displays and data storage—and sparked a global race to perfect the materials. He made those trailblazing lasers and their glowing cousins, light-emitting diodes (LEDs), at Tokushima, Japan-based Nichia—and became a sort of national folk hero in the process. (When Nakamura is in Tokyo, subway riders accost him for his autograph.)

Now, having moved to an academic post in the United States, he is at it again—caught up in an intense worldwide competition. That's because the bright blue emitting devices that are the progeny of his original inventions provide a key stepping stone in a high-stakes effort to produce white-light LEDs that are sufficiently cheap, pleasing, and efficient to crush Edison's almighty light bulb—and radically transform the $40 billion general-illumination industry.

Briskly crossing a courtyard, Nakamura enters a semiconductor test room, and grad student John Kaeding hands him a plastic container bearing a translucent Oreo-size disc. Nakamura sits on a stool and touches a test electrode to a spot near the disc's center. The disc is made of sapphire and coated with at least 30 invisibly thin layers of materials whose fundamental workings are not fully understood but whose properties astonish. Instantly, a bluish-green glow

emanates. Nakamura lifts the electrode and touches a spot closer to the disc's edge; it shines a grassy green. A third spot is dimly aquamarine; a fourth, violet; a fifth, bright blue—the color needed to create a solid-state device that produces white light.

Nakamura appears pleased, yet bright as this blue is, he knows immediately that it's not bright enough. That's why his grad students spend balmy California nights slaving over the 1,000 °C ovens in which these materials are grown, tweaking chemistries and temperatures, changing substrates, altering flow rates of gases. "We try, try, try," Nakamura says. A breakthrough, he adds, "could come in three years; could come today or tomorrow." But let there be no mistaking his goal: "I want to replace all the conventional lighting."

He's not the only one. Dozens of companies and academic groups like Nakamura's Solid State Lighting and Displays Center are feverishly seeking to produce a new kind of lighting by developing bright white LEDs *(see "Lighting the Way," p. 36)*. Indeed, just as transistors replaced vacuum tubes, LEDs promise to replace today's glass-encased incandescent and fluorescent light bulbs: LED lights use far less electricity than an average light bulb, and they shine for a far longer time before burning out.

Most researchers are, like Nakamura, pursuing LEDs made of such semiconducting materials as gallium nitride; a few other groups are developing more exotic organic light-emitting diodes (OLEDs), which are like plastic sheeting and herald the day when softly glowing patches of material replace ceiling fixtures and luminescent curtains brighten living rooms. Entrants in these races include lighting giants such as General Electric and Osram Opto Semiconductors, along with electronics companies such as Philips and Agilent Technologies, whose joint venture, Lumileds Lighting in San Jose, CA, makes one of the world's highest-power white LEDs.

The first results are already visible. Early white LEDs are widely sold in flashlights and head-mounted hiking lamps. Visitors to the Jefferson Memorial in Washington, DC, see a rotunda bathed in white LED light. As costs fall, efficiency rises, and the quality of the light improves, white LEDs should bust out of these niche applications and displace billions of conventional light fixtures in factories, offices, and homes. "It's not going to just change the light bulb; it will change the lighting paradigm," says Arpad Bergh, president of the Optoelectronics Industry Development Association, a Washington, DC-based industry group.

The new lighting technology would also dramatically cut electricity demand. According to a study commissioned by the U.S. Department of Energy, widespread adoption of next-generation white LEDs for lighting could, by 2025, slash electricity consumption by 10 percent worldwide, cutting $100 billion per year from electric bills and saving $50 billion in averted power-plant construction costs. "Lighting is a major contributor to the use of electricity. Collectively we could save half the energy we use on lighting," says George Craford, chief technology officer at Lumileds. "Make lighting more efficient and the question of building new power plants starts to go away."

IN TIME, FIERCE GLOBAL COMPETITION WILL DELIVER BIG JUMPS IN WHITE-LIGHT LED EFFICIENCY. "WE TRY, TRY, TRY," SAYS NAKAMURA. "IT COULD COME IN THREE YEARS; COULD COME TODAY OR TOMORROW."

WHITEOUT CONDITIONS

Anyone who has ever tried to change a lit light bulb has touched upon the problem with today's lighting technology. Fingers get scorched because about 95 percent of the electricity entering an incandescent bulb is wasted as heat. Fluorescent bulbs do much better, converting 20 to 30 percent of electricity into light. But even that pales beside the potential that LEDs offer. In theory, at least, an LED can convert almost 100 percent of its electrical power into light. Developers have not yet attained such perfection, but the efficiencies of the best white-light LEDs being produced are already about halfway between those of incandescent and fluorescent fixtures.

And although conventional lighting has already pretty much maxed out in efficiency, that's not the case with solid-state lighting. LEDs, which work on an entirely different physical principle, have at their core neither the tungsten filament of a conventional light bulb nor the gas of a fluorescent tube. Rather, they use crystalline layers that convert electrical input into optical output at a color determined by the exact composition of the material.

The colored LEDs that are the main ingredients of white-light sources have already made a dramatic impact. Take the ordinary red stoplight. In a conventional setup, one big, inefficient incandescent light bulb sits behind a red filter; the bulb guzzles about 150 watts of electricity and lasts about a year before it burns out, sometimes snarling traffic until the local highway department rushes out with a bucket truck to change it. In a growing number of traffic lights, though, a dozen or so red LEDs sit behind a clear lens, consume about 15 watts, and control traffic for five or more years before requiring replacement.

According to the California Department of Transportation, replacement of conventional traffic-light bulbs with LEDs—red, yellow, and most recently, green—has trimmed at least $10 million from the state's annual electric bill. And nationwide, according to Strategies Unlimited, a market research firm in Mountain View, CA, LED traffic lights are becoming commonplace: as of 2002, 39 percent of red lights and 29 percent of green lights used LEDs.

But coaxing LEDs to produce white light is a much tougher problem. LEDs inherently produce a single color. Producing what the eye perceives as white light requires the generation of many hues together (white itself is not actually a "color"). The easiest way to make white is to start with one LED—either blue or ultraviolet—and add materials called phosphors. The phosphors absorb those high-energy photons and generate lower energy ones, such as yellows and reds. Most of today's white LEDs pair a blue



Blue period: Shuji Nakamura, pioneer in blue LEDs, is now one combatant in the white LED race.
PHOTOGRAPH BY HENRIK KNUDSEN

LED with a yellow phosphor. But the resulting white lacks a full spectrum of colors and is therefore less pleasing to the eye than incandescent light; as with fluorescent tubes, which also use phosphors, skin can look a bit sickly. The newer white LEDs are better: they pair an ultraviolet-emitting LED with phosphors that put out light at a range of colors, which mix to make white *(see "White LED Anatomy," below)*. Any device that uses phosphors, however, loses some efficiency in the process.

Quality of lighting aside, developers must solve an even more fundamental problem before LEDs can replace the ubiquitous white light bulb: the white LEDs now being produced or developed all cost many times as much as an ordinary light bulb. "Nobody will pay 20 bucks for a light bulb–even if it lasts 500 times longer and uses half the electricity," says Frank Steranka, vice president for research and development at Lumileds.

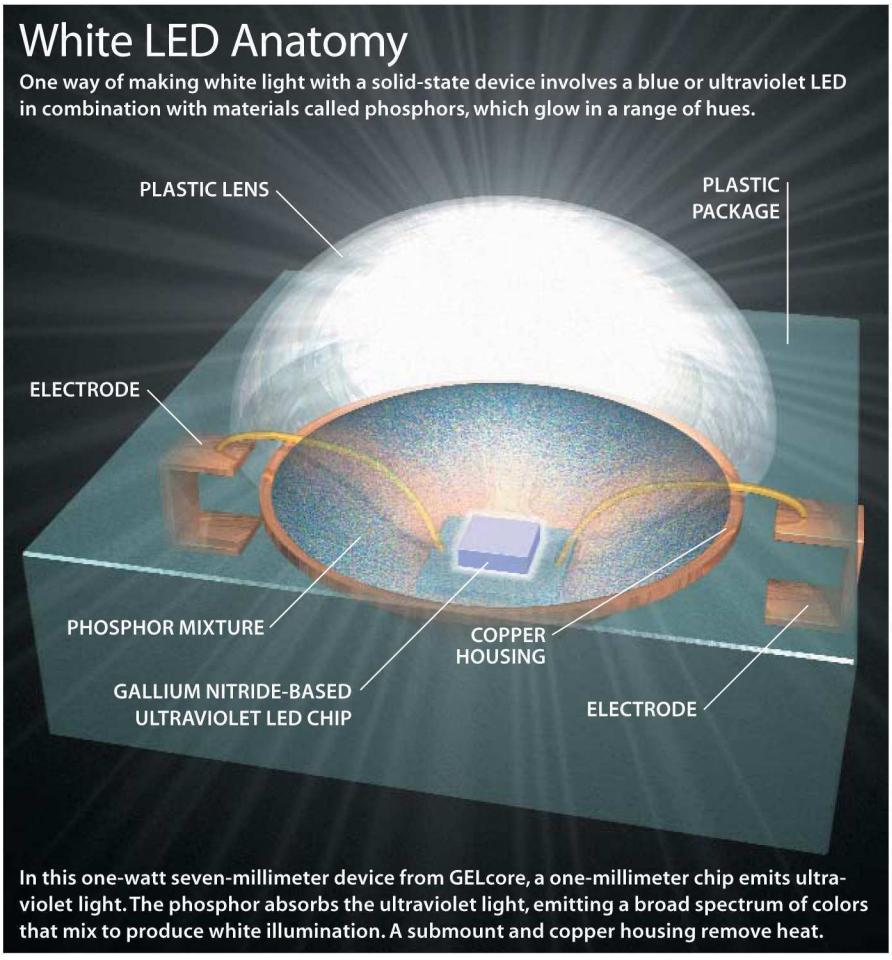
Overcoming the hurdles of efficiency, color, and cost is what the global race is all about. And advances on these fronts will soon drive wider adoption of LED lighting technology, says Robert Steele, director of optoelectronics at Strategies Unlimited. "In the next five years, they'll continue penetrating a variety of specialty markets like decorative lighting and entertainment lighting. In five to 10 years, they will start to penetrate the commercial and industrial market," Steele says. Next stop perhaps: your kitchen or living room.

GETTING THE LEDS OUT

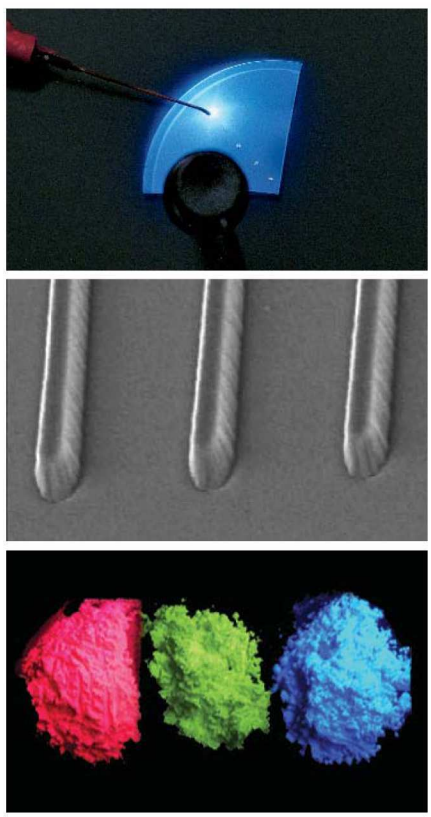
A white LED is only as good as its weakest component. Its performance depends on such factors as the purity of the semiconductor materials, the shape of the phosphor crystals, and even how well the lit device is able to dissipate heat. To bring white LEDs from the lab into broader markets will require improvements—and cost reductions—in all of these elements.

The job starts in a very hot oven. The key ingredient—gallium nitride—is born from gases fed into a superheated chamber. There, molecules containing gallium and nitrogen break apart, and crystals of gallium nitride begin to grow atop a sapphire substrate (in a process akin to the making of computer chips). It takes hours to deposit the dozens of layers, each with a slightly different chemistry. And it is far from a perfect process. A single sample, depending on where it is energized, can produce light of several different colors—which is why Nakamura is poking and prodding his materials so meticulously. Moreover, subtle differences in the arrangement of atoms can result in efficiency-robbing regions that look like vertical tunnels in the material.

Improvement of efficiency calls for growing crystals without those tunnels. Researchers at Sandia National Labs in Albuquerque, NM, believe they have a simple method for doing that, thus producing brighter LEDs. They start by etching grooves into the substrate, leaving a series of thin sapphire ridges, each about one micrometer wide. These ridges act like floor joists. The gallium nitride grows atop the sapphire ridges and moves sideways out over the grooves. Experiments have shown that this method reduces the number of defects by two orders of magnitude—and boosts brightness tenfold.

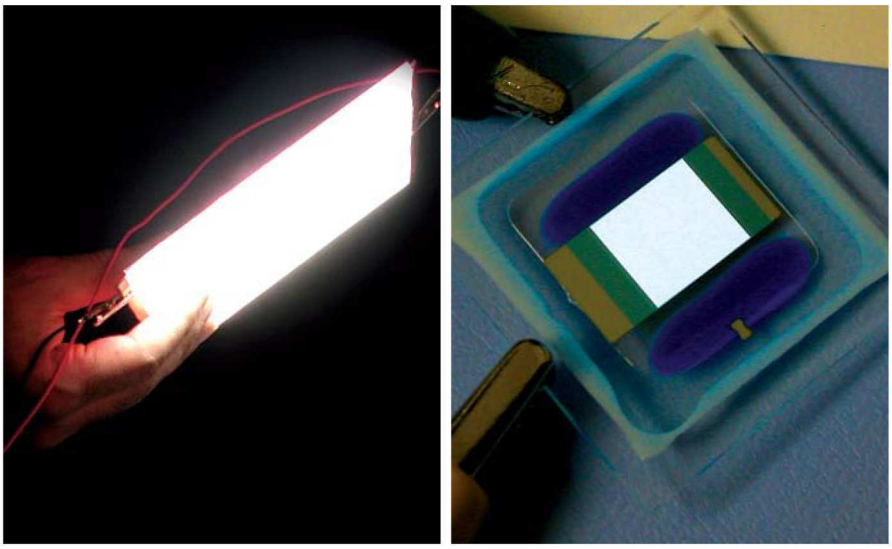


In this one-watt seven-millimeter device from GELcore, a one-millimeter chip emits ultraviolet light. The phosphor absorbs the ultraviolet light, emitting a broad spectrum of colors that mix to produce white illumination. A submount and copper housing remove heat.



Brighter whites: Improving white LEDs calls for brighter blue emitters (top), substrate modifications such as one-micrometer-wide ridges (center), and more efficient phosphors (bottom).

INFOGRAPHIC: JOHN MACNEILL, SOURCE: GELCORE; PHOTOGRAPHS: HENRIK KNUDSEN (TOP); COURTESY OF SANDIA NATIONAL LABS (CENTER); COURTESY OF GENERAL ELECTRIC (BOTTOM)



Glowing plastic sheets: Organic LEDs could provide flexible light fixtures that hang on walls and ceilings. Prototypes have been built by General Electric (left) and Universal Display (right).

Even when the material itself is efficient, the light must go where it's needed. Much of the light produced by a typical blue LED bounces around within the structure and is wasted. Nakamura's group at Santa Barbara is adding mirror-like nanostructures, just 50 nanometers wide, to certain crystalline layers. Steven DenBaars, a materials scientist who works with Nakamura, says that adding the nanostructures increases by 50 percent the light that gets reflected out of the device. But because such layers have not yet been integrated into a finished LED, the full payoff is uncertain.

Size matters too. A big LED chip gives off more light than a small one. Pursuit of a bigger LED has been a focus of the work at Durham, NC-based Cree, which makes some of the brightest blue LEDs on the market and is one of several corporations that have partnered with Nakamura's Santa Barbara lab. Last year Cree introduced an LED chip measuring 900 by 900 micrometers. It provides nine times the light-emitting surface area of the 300- by 300-micrometer chips that had been the industry standard. This expansion yields a simpler, hence cheaper, device, says Cree vice president Norbert Hiller. Lumileds, too, is developing larger chips and was able to deliver one of the world's brightest white-light LEDs: a five-watt device that puts out as much light as a 10-watt incandescent bulb.

Advances are also needed in phosphors. That's exactly what GELcore—a joint venture of General Electric and Somerset, NJ-based Emcore—says it has achieved. Starting with LEDs that emit ultraviolet light, researchers at GE's Global Research Center in Niskayuna, NY, went to work improving the phosphor recipes developed for the company's ordinary fluorescent light tubes. The result: they increased by a factor of 100 the ability of the phosphor to absorb energy, says Charles Becker, a physicist and manager of LED lighting research at GE's research center.

Thanks to this development, GE says it is close to launching a white-light device that can produce 30 lumens per watt, a considerable improvement over the 10 to 15 lumens per watt rating that consumers are accustomed to seeing on the boxes of typical incandescent bulbs. What's more, the device is designed to last 50,000 hours—about six times the typical incandescent's lifetime. GELcore plans to begin selling LEDs that use this technology later this year and aims to push light output to 50 lumens per watt within two years, says Becker.

Just about every company in the white-light LED game is tackling these and other methods. One approach skips the phosphor conversion process altogether and instead produces white light by combining the output of red, green, and blue LEDs. Lumileds, for instance, is already assembling emitters of these three colors to produce backlighting for displays such as those used in cell phones and laptop computers. While bypassing the phosphor adds cost and difficulty, this technique increases efficiency.

Unfortunately, the materials of each color LED degrade at different rates. Stabilizing the white, therefore, requires sensors and electronics: as the sensor records a decline in an LED's output, it directs the circuit to compensate by feeding more power to the chip. Steranka says that making this approach work for a low-cost general-illumination product calls for volume-driven cost reductions in such electronics, as well as more efficient individual LEDs. But the payoff would be further gains in efficiency—a goal Steranka is confident can be achieved. "People know how to do to it," he says. "It's not rocket science."

THE DARK HORSE OF THE WHITE LED RACE IS THE ORGANIC VERSION: PLASTIC MATERIAL THAT COULD SERVE AS GLOWING WALLPAPER. IN JUST 18 MONTHS, LAB TESTS HAVE SHOWN A DOUBLING IN EFFICIENCY.

PLASTIC LIGHT

There's a dark horse in the white-light race: the organic light-emitting diode, or OLED. Whereas an ordinary LED makes a bright point of light, the organic variety resembles a patch of softly glowing plastic. Mass production of these products could be as simple as ink-jet printing because there is no need for the costly chip-fabrication facilities that make LEDs so expensive. Someday this technology might lead to flexible lighting fixtures that hang on walls, ceilings, and even furniture.

The main impetus for OLED development is coming from companies that seek backlighting for cheaper, brighter displays. But the technology is improving rapidly, approaching the point where it could be practical for illumination. Barely 18 months ago, GE researchers proudly touted a 2.5- by 2.5-centimeter white-

COURTESY OF GENERAL ELECTRIC; COURTESY OF UNIVERSAL DISPLAY

light OLED that produced only 3.8 lumens per watt. Today, says Anil Duggal, manager of the light energy conversion program at GE Global Research, the company can show off a 15- by 15-centimeter prototype—about the size of a compact-disc case—with double the efficiency of the earlier OLED.

And just as Nakamura is adding nanostructures to LEDs, Duggal is adding particles to the OLED substrate to provide more chances for the light to zip from the surface of the device, rather than being absorbed internally. Employing such tricks could make OLED-based white lights competitive with fluorescent tubes within a decade, Duggal says. "There is no problem getting to high brightness, but lifetimes are still an issue, and efficiencies are an issue," he says.

To speed development, Ewing, NJ-based Universal Display is working with a new class of OLED materials. Invented in 1999 in collaboration with the University of Southern California and Princeton University, these materials incorporate atoms of heavy metals such as platinum, surrounded by carbon-based molecules that amount to "organic shrubbery," says Janice Mahon, vice president of technology commercialization at Universal Display. Last year the company and its academic partners used this material to build a white-light OLED prototype that achieved 11 lumens of light per watt of electricity. That device was made with a single OLED material that can emit a broad spectrum of colors. But the company is also pursuing a white-light source that relies on a combination of different materials, some emitting red, some blue, and others green. Universal Display expects to build a prototype this spring, Mahon says.

A more far-out vision for OLEDs embeds glowing specks of inorganic crystals into the lighting device. Each of these "quantum dots" is a cluster of cadmium selenide atoms one to five nanometers across. At that scale, the strange rules of quantum physics take over, and the wavelength of the emitted light depends purely on the size of the cluster. Late last year two MIT researchers—chemist Moungi Bawendi and electrical engineer Vladimir Bulovic—showed that a sprinkling of quantum dots could brighten an OLED significantly. But right now, Bulovic says, the quantum dot white OLED is only "a good proposal—it's far away from being a proved fact."

THEY'RE A NICHE NOW, BUT BY 2025 EFFICIENT LEDS FOR ILLUMINATION COULD CUT $100 BILLION FROM GLOBAL ELECTRICITY COSTS AND ELIMINATE THE NEED FOR $50 BILLION WORTH OF POWER PLANTS.

Lighting the Way

COMPANY	TECHNOLOGICAL DISTINCTION
Cree Durham, NC	Bright blue light-emitting diodes (LEDs); silicon carbide substrate
Nichia Tokushima, Japan	First blue LEDs
Lumileds Lighting San Jose, CA	Bright white LEDs; unique heat-sink package
Osram Opto Semiconductors Regensburg, Germany	Chip faceting for bright white LEDs
GELcore Valley View, OH	Phosphor that promotes better-quality white light
General Electric Global Research Center Niskayuna, NY	White organic LEDs (OLEDs)
Universal Display Ewing, NJ	White OLEDs

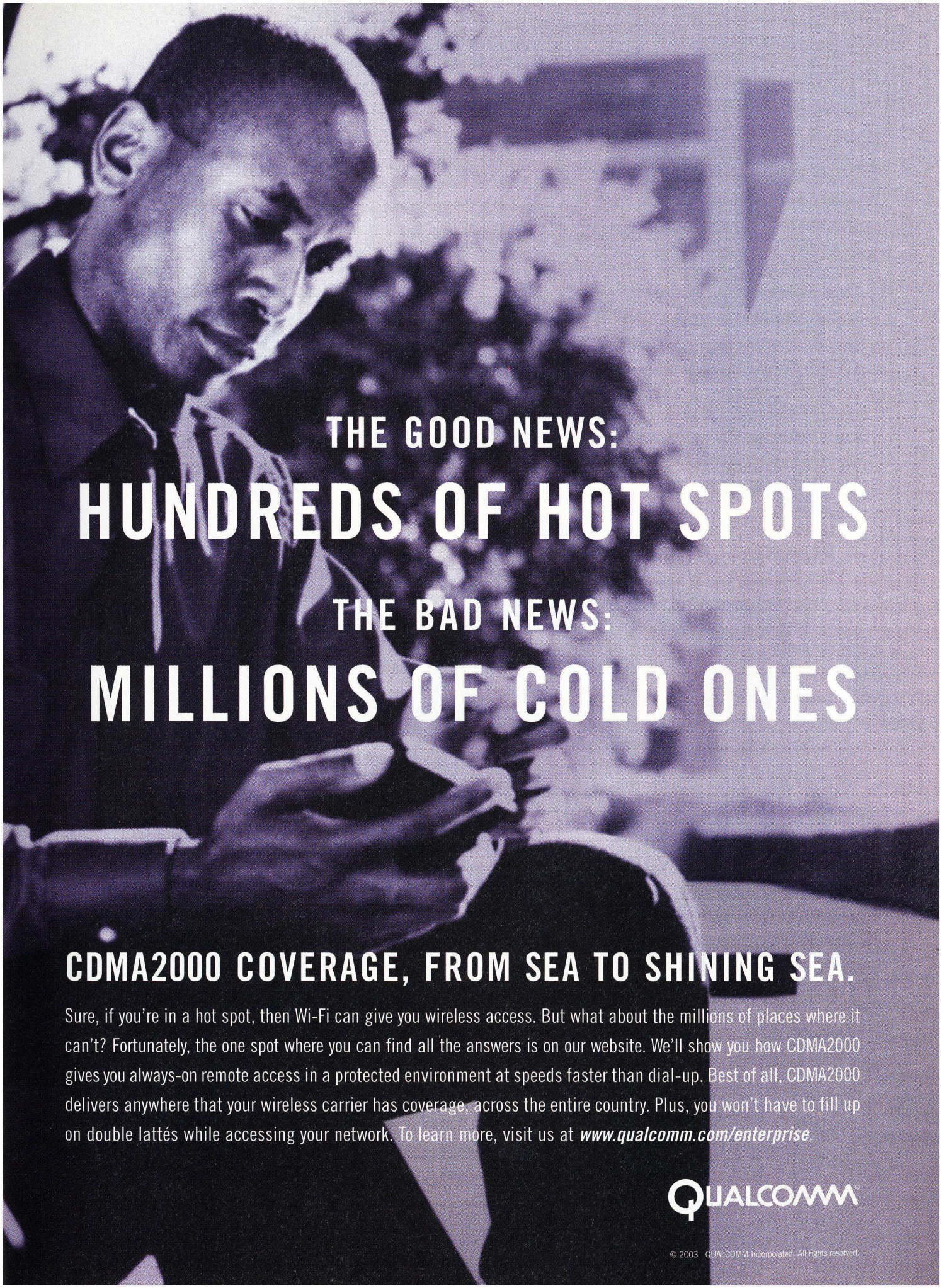
Regardless of whether quantum dots get their moment to shine, the future of illumination appears solid—solid-state, that is. The pitched competition across corporate and academic labs promises to upend the century-old lighting industry. In addition to Lumileds and GELCore in the United States, the leading players include Nichia and Toyoda Gosei in Japan and Osram Opto Semiconductors in Germany. "Those would be the five who have advanced the art the most," says Steele of Strategies Unlimited.

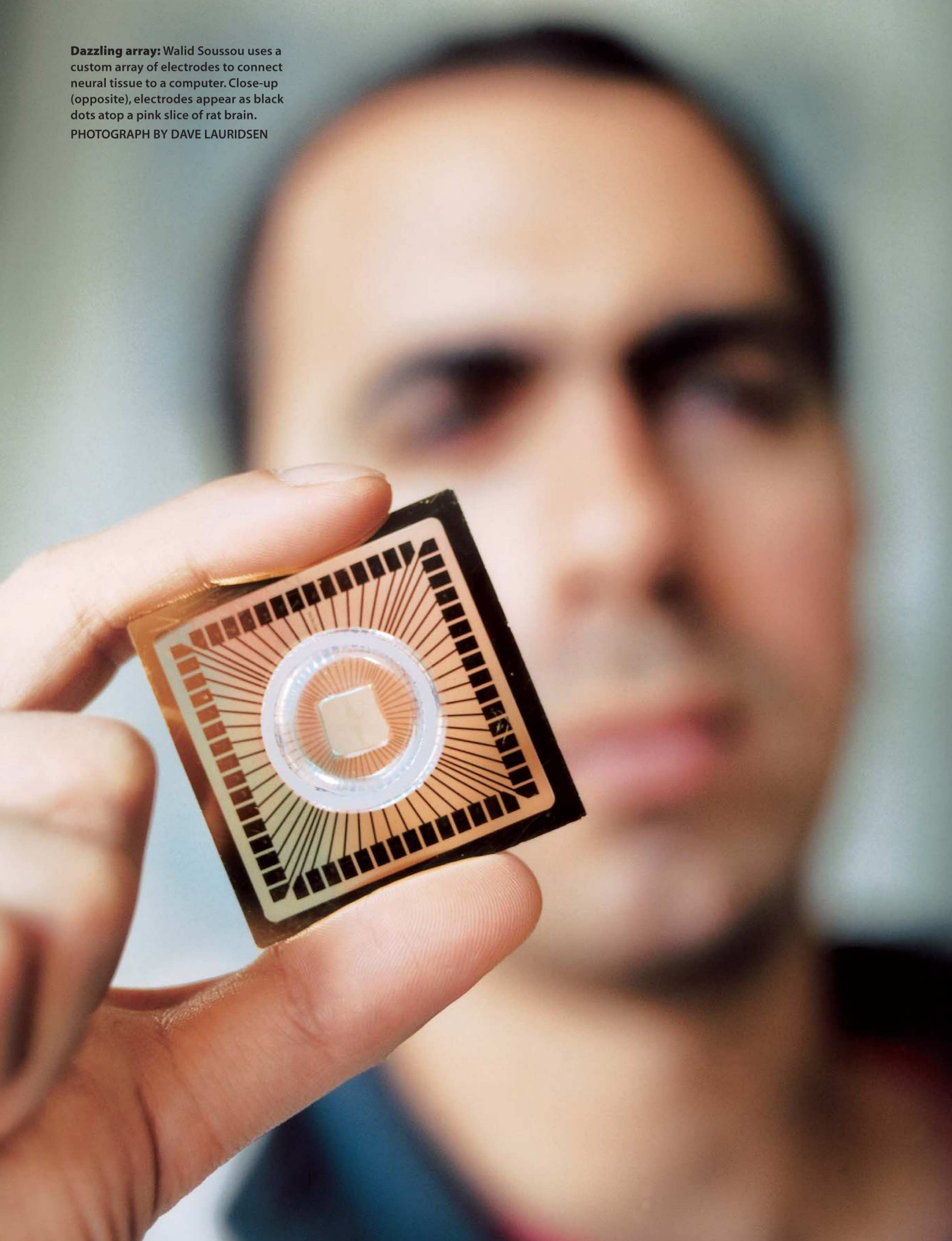
While for the next few years these and other companies are chasing big markets in backlighting for cell phone displays and automotive instrument panels, LED developers will increasingly find paradise beyond the dashboard lights. By 2007 the LED illumination business will top $500 million, according to Strategies Unlimited—of which $135 million will be for white-light LEDs.

And that's just a taste of what's to come: the field is still wide open for technology breakthroughs. "It is always possible that someone from left field is going to come in and do something dramatic," Steele says. Indeed, he and other industry observers agree, the great number of players pursuing solid-state lighting technology—and the great theoretical potential of LEDs—makes major advances in white-light LED illumination inevitable. It's only a question of who will make that next breakthrough.

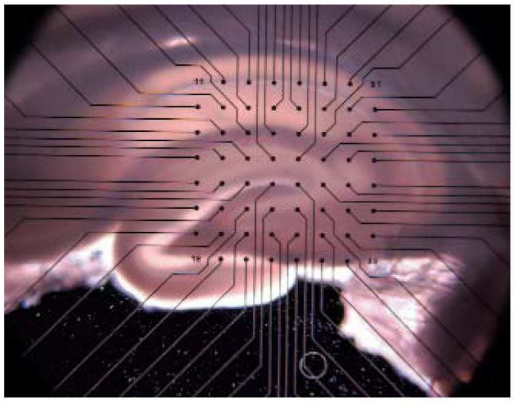
In the test room at Nakamura's Santa Barbara laboratory, grad student John Kaeding describes the researchers' efforts by citing the adage about 10,000 monkeys pounding on 10,000 typewriters and eventually producing a work of Shakespeare. That old saw is new to Nakamura, but when the light pioneer absorbs the point, he nods vigorously: "Yes, yes," he says. With so many labs attacking the technology from so many angles, he believes that someday, somewhere, a researcher will open an oven and pull out a material that can emit a blue glow of unmatched brilliance—radically advancing the way we light our world.

No wonder the shades are drawn on Nakamura's windows. TR


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THE BAD NEWS:
MILLIONS OF COLD ONES
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Dazzling array: Walid Soussou uses a custom array of electrodes to connect neural tissue to a computer. Close-up (opposite), electrodes appear as black dots atop a pink slice of rat brain.
PHOTOGRAPH BY DAVE LAURIDSEN



COURTESY OF WALID SOUSSOU AND TED BERGER

MIND-MACHINE MERGER

A $24 MILLION GOVERNMENT INITIATIVE IS JUMP-STARTING RESEARCHERS' EFFORTS TO LINK BRAINS AND COMPUTERS. THE NEW PUSH COULD YIELD THOUGHT-CONTROLLED ROBOTS, ENHANCED PERCEPTION AND COMMUNICATION—AND MIGHT EVEN MAKE YOU SMARTER.

BY GREGORY T. HUANG



Direct connections: University of Southern California researchers probe the behavior of specific parts of a brain slice in order to build a better brain-machine interface.
PHOTOGRAPH BY DAVE LAURIDSEN

Ted Berger is a mind reader. The minds of rats, that is. In his lab at the University of Southern California, the neurobiologist places a tiny array of electrodes onto a slice of a rat's brain in a petri dish. With the flip of a switch, graduate student Walid Soussou starts the flow of electrical signals into the tissue. The brain cells respond by generating their own electrical impulses. This swirling pattern of neural signals is picked up by the electrodes and appears on a nearby computer screen as a wash of colors ranging from brilliant red to dark blue.

For the next few hours, Berger and his team will map out the circuitry behind one of the brain's most complex functions: memory. It's basic research, but they are doing it with a big technological goal in mind. Berger's group aims to use the information to build an advanced "brain-machine interface"—a device that links the biological circuits of a brain to the silicon circuits of a computer—that will change how the mind thinks.

In recent years, research groups around the country have implanted electrodes in the brains of animals—and even a few humans—and have used signals detected by those electrodes to move robot arms, levers, and cursors on computer screens *(see "Other Brain-Machine Research," p. 45)*. The aim of the work has been to give paralyzed patients the ability to control prosthetic limbs and simple communication tools. But Berger's objective is even more far-reaching: to build a computer chip that will restore the cognitive abilities of the brain itself, aiding memory in patients who suffer from such neurological disorders as Alzheimer's disease and stroke and perhaps eventually enhancing the abilities of healthy minds. To do so, the researchers have to understand neural processes that may be more complicated than those that govern, say, the control of a prosthetic arm. "It's one of the most ambitious projects in the whole field," says Christof Koch, an expert on computation and neural systems at Caltech.

As bold as it is, Berger's team is not the only group breaking new ground in what researchers sometimes call neural prostheses. A two-year, $24 million program from the U.S. Defense Advanced Research Projects Agency, launched last fall, is rapidly expanding the boundaries of brain-machine interface research. The six projects funded by DARPA's program—including Berger's at the University of Southern California—aim to develop technologies that will not only restore but will also *augment* human capabilities, says Alan Rudolph, program manager of the DARPA initiative. This coordinated, well-funded "big science" approach to understanding how minds and machines can interact, he says, could have "transformational consequences for defense and society."

The effort will yield a new generation of electrodes, computer chips, and software that might eventually equip soldiers, for example, to control superfast artificial limbs, pilot remote vehicles, and guide mobile robots in hazardous environments, using only the power of their thoughts. Even more remarkable, such devices could enhance decision-making, upgrade memory and cognitive skills, and even allow one person's brain to communicate wirelessly with another's.

Although such applications are as speculative as they are spectacular, scientists no longer view them as pure fantasy. Their new optimism is fueled in part by a host of recent advances in neuroscience, interface hardware, and signal processing. And the influx of money certainly doesn't hurt. "DARPA is putting much larger resources into the area than has ever been seen before," says William Heetderks, director of the Neural Prosthesis Program at the National Institutes of

Health. And because researchers in this field have no shortage of innovative ideas, he adds, the new funding "will have a tremendous effect."

REMOTE CONTROL

Among the rolling hills of Durham, NC, Duke University's Miguel Nicolelis is attempting to teach old monkeys new tricks. But first, their brains must learn to listen.

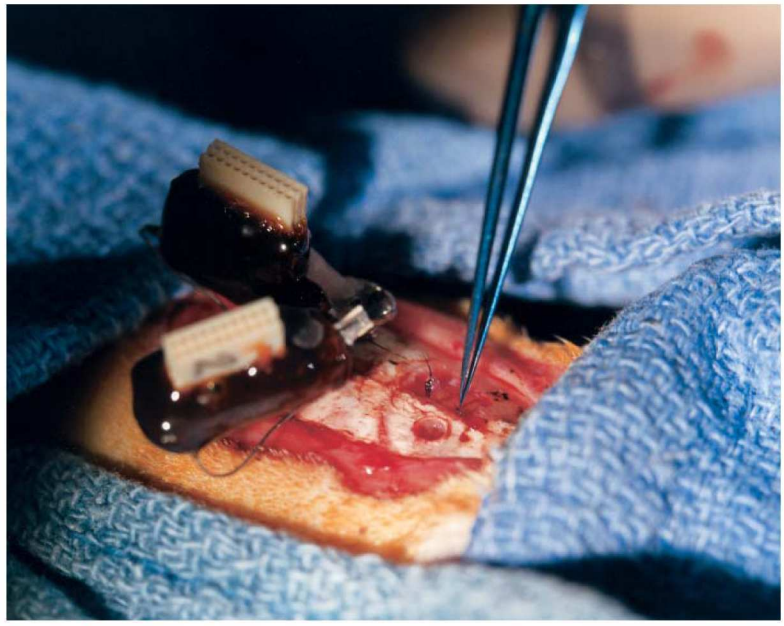
Over the last few years, Nicolelis and his team have shown that brain signals picked up by electrodes implanted in animals' brains can provide rudimentary control of robot arms. But there's a hitch: the animals don't know they are controlling anything. To get to the point where animals—and eventually humans—can take on more sophisticated tasks, Nicolelis says, real-time communication between mind and machine must become a two-way street.

So in Nicolelis's lab a rhesus monkey is not only controlling a robot arm through brain signals picked up by electrodes implanted in its head, it is also getting feedback from the robot—for now, in the form of a cursor on a screen that shows the robot's movements. Kept in separate rooms, the monkey and robot arm are linked via cables, a microcomputer, and a parallel processor. The next step will be to implement tactile feedback. When the monkey tries to use the robot arm to grab a rubber beer mug, the robot arm will send signals to force transducers placed on the animal's upper arm; these motors will vibrate vigorously when the robot's grip tightens. And eventually, Nicolelis says, the system could provide even more direct feedback by electrically stimulating sensory regions of the brain. "The trick is to give the right kind of feedback so the monkey's brain will incorporate the robot as if it were a part of its own body," he says.

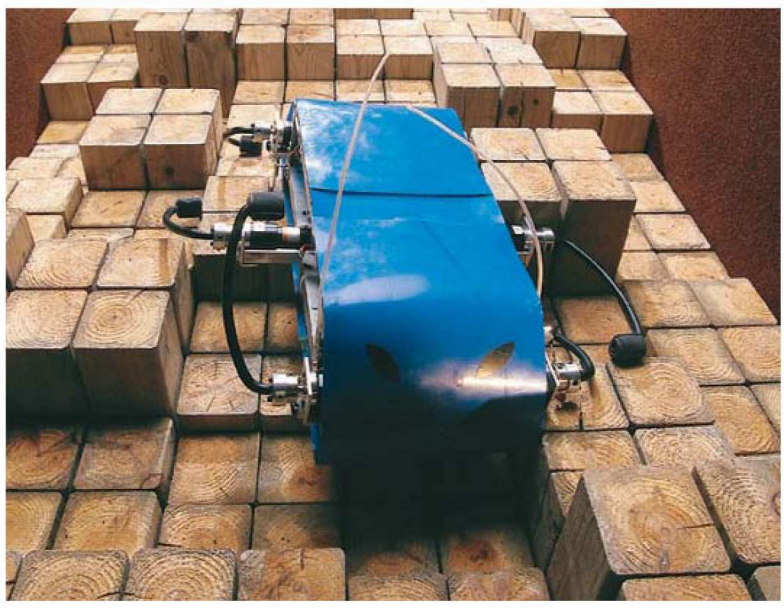
Once they "close the loop" of brain-machine interaction, Nicolelis says, researchers can begin to think realistically about designing systems whose physical capabilities surpass those of normal people. One example: by bypassing nerves and muscles and connecting the brain directly to a robotic limb, he says, it may be possible to cut reaction times by a factor of six. He predicts that many labs will demonstrate such augmentation of basic physical abilities over the next five years.

As Nicolelis works to replicate and augment such everyday capabilities as grasping and lifting, researchers at the University of Michigan are pushing brain-machine interfaces into new realms of physical control. Biomedical engineer Daryl Kipke and his team are teaching rats and monkeys how to guide the movements of a fleet of mobile robots using only their minds. Feedback is important, Kipke says, because it allows the animals to gain experience interacting with a device that is completely foreign—in this case a half-meter-long, six-legged robotic critter named RHex (pronounced rex).

For now, the agile robot must be either programmed to run in a certain direction or remotely directed by a hand-controlled wireless link. But brain-machine interfaces, the Michigan researchers say, could allow for faster and better-coordinated control. In the distant future, soldiers or rescue personnel—possibly at multiple locations—might plug their minds into a central computer to control a fleet of RHexes in the field. Guided by brain impulses, the robots would carry out search-







Rat-driven robot: In Daryl Kipke's lab, scientists implant electrodes into a rat's brain (top) and monitor its neural signals on a computer (center). Eventually, the signals will control a mobile robot (bottom).
PHOTOGRAPHS (TOP AND MIDDLE) BY CHRIS LAKE

PETER MENZEL (ROBOT)



Wireless ambitions: The wires that connect a rat's brain to a computer could eventually be replaced with a wireless transmitter.
PHOTOGRAPH BY CHRIS LAKE

and-rescue missions in war zones and disaster areas, while sending audio, visual, and tactile feedback to their controllers. "That's the home run," says Kipke.

Although reaching that goal is probably still decades away, Kipke's team is working toward it by extracting signals from neurons in the areas of the brain that are involved in planning and executing movements. With all the noise from surrounding cells, it's like trying to listen to specific conversations in a baseball stadium. Within a year, the researchers will surgically implant arrays of silicon electrodes—each no wider than a hair—in an animal's brain and connect each array to a flexible low-power circuit that looks like a one-square-centimeter Band-Aid on the animal's skin. The circuit will speed up the overall processing of the signals and allow them to be sent wirelessly to a central computer. There, custom software will translate the signals into movements of a computer cursor, which the animal will watch. The next step, says Kipke, will be connecting the cursor to RHex's wireless control system so that when the cursor moves left, the robot does the same.

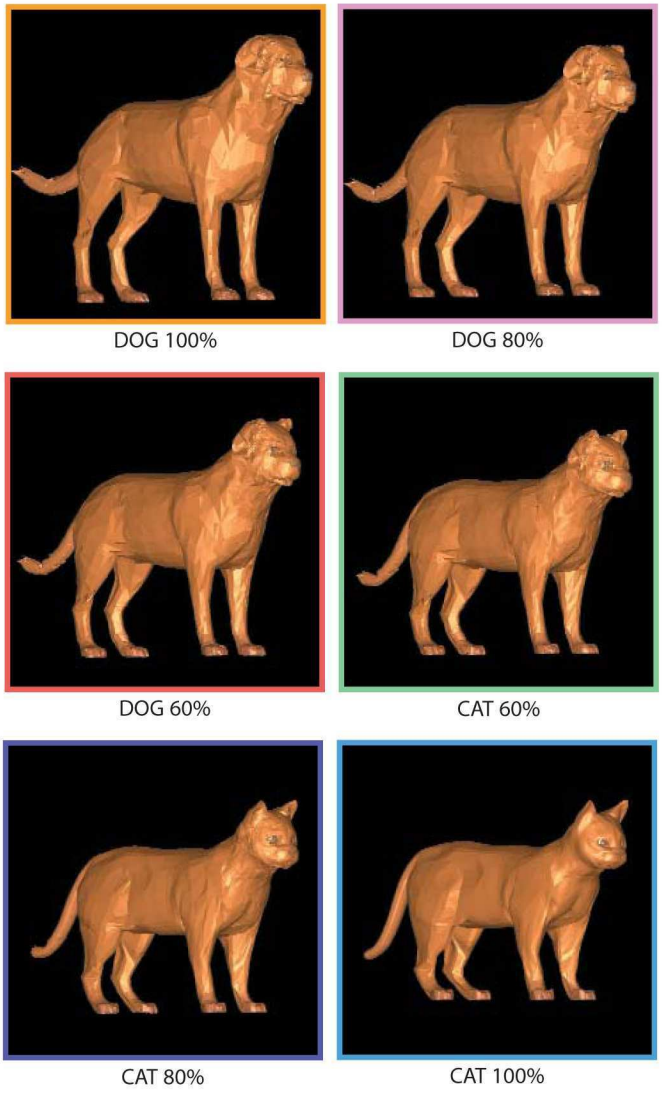
By summer the Michigan team, together with physiologist Dan Moran at Washington University, plans to have a monkey in St. Louis navigate RHex through an obstacle course in Ann Arbor, MI. The control signals will pass back and forth via the Internet, and the monkey will monitor a graphical representation of the robot's position and movements on a screen. The overarching goal of the current project is to test whether such interfaces can engage the brain—making use of both neural commands and feedback—to control increasingly remote and complex devices. "Within five years, we'll know if we can do this," Kipke says.

PUMPING UP PERCEPTION

While Nicolelis and Kipke are boosting the brain's ability to control external devices, others in the DARPA initiative are aiming to manipulate the brain's inner workings—specifically those that send, receive, and process sights and sounds. By tapping into the visual and auditory regions of the mind, researchers are testing whether such information can be transmitted between brains and computers to enhance perception and communication. If successful, the projects could lead to astounding new interfaces that enhance humans' ability to recognize faces, objects, and speech and to make decisions. They might even enable brain-to-brain wireless communication, says DARPA's Rudolph.

Before they can devise such systems, researchers must learn how to "read out" information from the brain, as well as "write in" information, says Tomaso Poggio, an expert on artificial intelligence at MIT. Poggio and MIT neurophysiologist James DiCarlo, both principal investigators in the DARPA program, are working with visual perception and object recognition in rhesus monkeys. The researchers will present objects such as abstract shapes, cars, and animals on a computer screen. One possible experiment is based on previous collaborations with MIT neuroscientist Earl Miller: the researchers could train a monkey to decide whether a computer-generated animal on a screen looks more like a cat or a dog *(see "Mind Readout," this page)*. Software would blur the line, creating, for example, an image that is 60 percent cat and 40 percent dog. While the mon-

Mind Readout

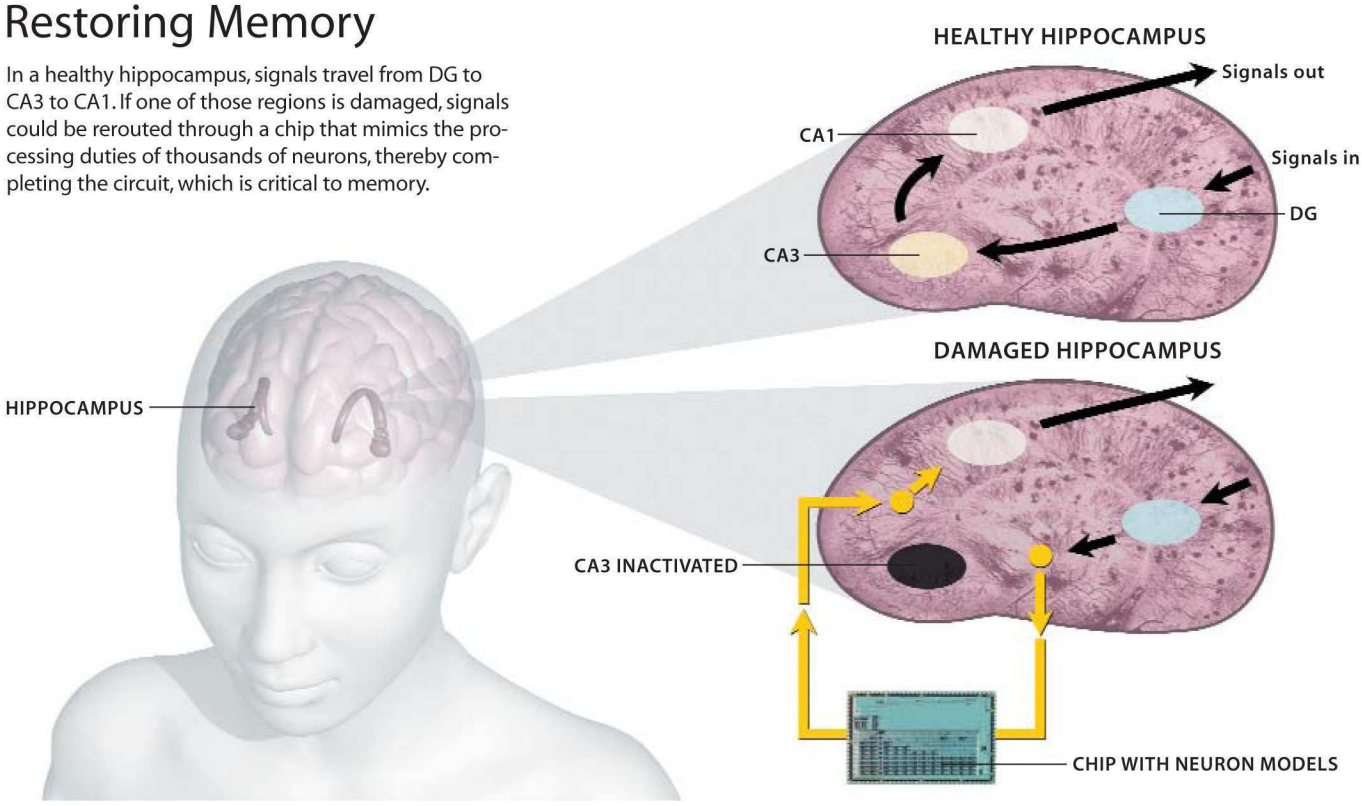


MIT researchers trained monkeys to decide whether computer-generated hybrid animals (top) look more like cats or dogs. Recordings from the brain (bottom) show certain neurons respond more strongly to the dog-dominant hybrids. The implication: it may be possible to read the monkey's perception directly from brain signals.

COURTESY OF DAVID FREEDMAN, MAX RIESENHUBER, TOMASO POGGIO, AND EARL MILLER

Restoring Memory

In a healthy hippocampus, signals travel from DG to CA3 to CA1. If one of those regions is damaged, signals could be rerouted through a chip that mimics the processing duties of thousands of neurons, thereby completing the circuit, which is critical to memory.



key is making its decision, the researchers would use implanted electrodes to record signals from neurons in the visual cortex: some of these cells fire when the monkey views a cat, others when it sees a dog.

A software model trained with data from previous trials would then process the brain signals and read out the monkey's decision. The researchers would test this prediction against the primate's voluntary response: pressing the "cat" or "dog" button. "We train the algorithm to associate the behavior of these neurons with the decision so that later, from the electrical activity of these neurons, we can predict what the monkey is seeing," says Poggio. On the basis of preliminary results, he says, the computer may be able to predict correctly 90 percent of the time, using signals from only a few hundred neurons.

The MIT researchers' next challenge, which could take at least two years to tackle, is to test whether they can write perceptions into the brain via electrical stimulation. They will start with simple images like lines and shapes. But eventually they may be able to inject tiny amounts of current into the brain of a monkey and trick it into *thinking* it sees a dog on-screen when in fact there is a cat—or even no image at all. This is doable in theory, says Caltech's Koch, a collaborator on the project. But the challenge is to zap just the right neurons—no small task, considering that 100,000 cells are packed into each cubic millimeter of the cerebral cortex and each cell makes hundreds of connections with others.

The ultimate vision is to connect the read-out and write-in technologies, enabling computer-mediated brain-to-brain communication. Under the DARPA initiative, scientists at Vanderbilt University propose to build and test such a system. As a first step, they plan to link neurons in the auditory regions of the brain of one monkey to similar cells in another monkey. The researchers will then play a sound that is audible to only one monkey and test whether the second monkey, sitting in a different room, responds.

But many scientists consider brain-to-brain communication to be a long shot. Aside from the challenge of sampling and stimulating enough of the right neurons, says the NIH's Heetderks, such a system would be limited in practice by its processing speed: speech communication requires more information flow than object recognition or motor control. "It could work," Heetderks says, "but it might take us three weeks to have the conversation we're having right now."

SILICON COGNITION

Back at the University of Southern California, Berger's team is pushing the farthest frontier of brain-machine interfaces. Once they have mapped out the signal patterns of several regions of the brain, the researchers plan to manipulate the ways the brain processes information and communicates with itself—in short, how the brain *thinks*. This work could one day lead to neural prostheses that restore and even enhance such cognitive processes as memory. Imagine going to the doctor to recover memories long since faded or buying hardware that sharpens your ability to remember people's names.

Berger's team is taking a baby step toward that vision by developing a computer chip that mimics the signal processing of the hippocampus, a spiral-shaped region of the brain that is instrumental in learning and forming memories. Fortunately, the information flow in the hippocampus of rats is straightforward, says Berger, and the circuit looks similar, though more complicated, in the human hippocampus.

What makes things challenging is that—at least in Berger's view—memory in the brain is represented in the dynamic firing patterns of neurons, not in a fixed arrangement of bits like

JOHN MACNEILL

that of a computer's memory. "If any part of the brain looks like RAM, we haven't found it yet," Berger says. And neurons are inherently tricky. To get one to fire, timing is everything: it may take a combination of impulses from surrounding neurons or repeated inputs from one messenger spaced in time just so.

To capture these dynamics, Berger's team has developed mathematical models of the individual neurons in question and has begun to implement the models in hardware. If neuron A sends a particular pattern of impulses to neuron B, says University of Southern California biomedical engineer Vasilis Marmarelis, the model tells you what pattern neuron B will send to neuron C. "It isn't sexy," he says, "but it's the first step of a very long journey." From there, the researchers will put thousands of neuron models onto a low-power silicon chip.

Later this year, says Berger, the proof-of-principle experiment will go like this: In a slice of a rat's hippocampus, the scientists will demonstrate that electrical signals from region A are processed by region B and sent on to region C. They will then remove neurons from region B and show that the output of region C is disrupted. Finally, they will reroute the signals through a prototype chip—in place of region B—to see whether that completes the circuit and produces the same overall pattern of signals as the healthy slice *(see "Restoring Memory," p. 44)*.

If this is successful, the next step will be to test the chip in an animal. Within three years Berger's group plans to turn its interface over to a team led by physiologist Sam Deadwyler at Wake Forest University. Deadwyler is training monkeys to remember clip art pictures flashed on a screen and to pick the images from a subsequent lineup. At the same time, he is recording signals from the hippocampus that allow him to identify which neurons are important for the task—and even to predict whether the monkey will choose correctly. When Berger's interface is ready, says Deadwyler, the researchers will temporarily inactivate the hippocampus so the primate can no longer do the task; then they will plug the chip into the affected area to see whether the interface can restore the monkey's performance.

Eventually, Berger and Deadwyler plan to determine whether the chip can augment memory: they will implant the chip in an animal whose hippocampus is intact. With the chip, the monkey might be able to remember a picture for a longer period of time or be able to pick it out of a larger lineup of distractions. In the future, says Deadwyler, it might be possible to connect a person's brain to hardware that makes memories last longer or that allows one to keep track of ever increasing amounts of information—like when you're dashing through a busy airport and need to remember a phone number for a few seconds. But don't expect to see this anytime soon. "We're a long way from improving on paper and pencil," says the NIH's Heetderks.

For one thing, Berger's group faces the skepticism of some scientists who don't buy into the fundamental premise that memory is constituted solely of dynamic patterns of neuron activity. And it faces many of the practical challenges other neural-prosthesis research teams grapple with. For now, nobody knows exactly which neurons—or how many—need to be tapped in order to achieve useful devices. Depending on the application, the researchers may need to access thousands of brain cells all at once. And there are computational hurdles they must overcome before the interfaces can process massively parallel streams of neural data in real time.

But perhaps the greatest technical challenge lies in physically connecting rigid hardware to delicate brain cells and sustaining those connections for months or even years at a time, says John Chapin, a physiologist at the State University of New York Downstate Medical Center who helped pioneer methods for accessing brain signals in the mid-1990s. Because neurons continually shift their positions and alter their connections, the interface must be flexible, biocompatible, and adaptable to changes in the signals it receives. With this in mind, DARPA's Rudolph is pushing to promote a standardized electrode platform across the initiative so that each team doesn't reinvent the wheel. But this is easier said than done. "Scientists would rather use each other's toothbrushes than each other's electrodes," says Caltech's Koch.

Even if the interface technologies work, they might face a long road to acceptance. Paralyzed patients anxious to gain enhanced physical abilities may be willing to accept the risks of surgery and to live with hardware implanted in their brains, but most healthy people would probably balk at the proposition. In fact, says Rudolph, "we really don't envision implanting healthy people with these kinds of devices." The key to being able to restore or augment human capabilities, he says, will be gaining access to the brain signals in an unobtrusive way—ideally, without wires, electrodes, or surgeries.

Before DARPA—or anyone else, for that matter—will invest in that next generation of brain-signal-detection technology, researchers must determine whether neural prostheses will be practical in their new applications. "If successful," says Rudolph, "we will have seeded the important work to demonstrate that this can be done and—if a noninvasive tool can be found to extract the same kinds of information—that human performance enhancement can be envisioned." And though this vision is still years away, our minds may already be on the road to a new way of thinking.

Other Brain-Machine Research

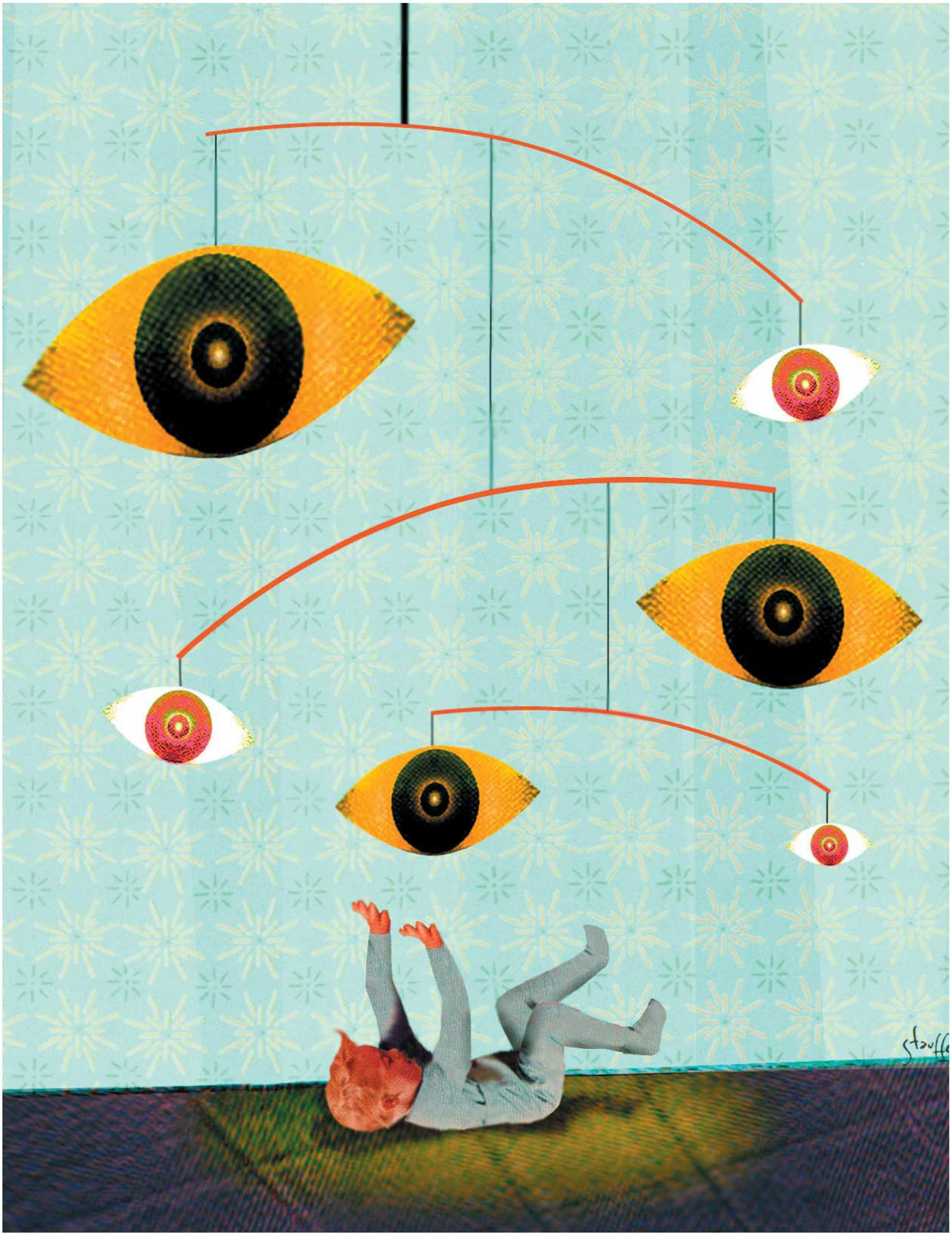
RESEARCHER	INSTITUTION	PROJECT
Richard Andersen	Caltech	Electrode systems for recording brain impulses
Niels Birbaumer	University of Tübingen (Germany)	Noninvasive brain-signal detectors
John Donoghue	Brown University and Cyberkinetics (Providence, RI)	Neural prostheses that give paralyzed patients control over computers
Philip Kennedy	Neural Signals (Atlanta, GA)	First human tests of brain implants for restoring communication in completely paralyzed patients
Andrew Schwartz	University of Pittsburgh	Neural prostheses that control robot arms
Harvey Wiggins	Plexon (Dallas, TX)	Hardware and software for recording and analyzing brain signals

PART TWO

SURVEILLANCE NATION

In the name of convenience, efficiency, and security, we're creating a world in which our every movement, transaction, and indiscretion can be electronically tracked. But if we ensure that emerging surveillance technologies are designed in ways that deter misuse, we may not have to forfeit our privacy in the bargain.

By Dan Farmer and Charles C. Mann
ILLUSTRATIONS BY BRIAN STAUFFER



"Give me Duquesne minus 7, for a nickel."

It was February 1965 on a lonely section of Los Angeles's Sunset Boulevard, and Charles Katz, one of life's little losers, was placing an illegal sports bet over a public telephone. Unbeknownst to Katz, however, the FBI had placed a microphone atop the telephone booth to record this small-time gambler's conversations.

Engineers often mock the law for lagging behind technology. In fact, the law is often far ahead of it. This time it was ahead by nearly 200 years, for after Katz's arrest his lawyers argued that although the framers of the Constitution could not possibly have encountered tape recorders and telephone booths, the Fourth Amendment's ban on "unreasonable" searches nonetheless covered them. Because the FBI had no search warrant, Katz's lawyers said, bugging the phone booth was illegal. In a landmark decision, the Supreme Court agreed, affirming for the first time that electronic surveillance was—constitutionally speaking—a search. "No less than an individual in a business office, in a friend's apartment, or in a taxicab," the majority declared, "a person in a telephone booth may rely upon the protection of the Fourth Amendment."

Equally important was Justice John Harlan's concurring opinion. The government, he argued, could not freely eavesdrop in any place where people have a "reasonable expectation of privacy"—a phrase that even now, four decades later, resonates in the laboratory of Wayne Wolf. An electrical engineer at Princeton University, Wolf leads a research team that is creating a tiny, inexpensive video camera one might glibly describe as a lens glued to a chip. In theory, the camera could be the size of a postage stamp and cost as little as $10, "small and cheap enough to scatter by the dozen," as Wolf puts it. The laws of optics dictate that tiny lenses make low-resolution images, so the researchers are developing software that melds video from multiple cameras located in a single area, producing sharp, real-time images of the entire space. "You could stick them up all over a building and know *exactly* what was going on inside," Wolf says. "A lot of people would find a use for that."

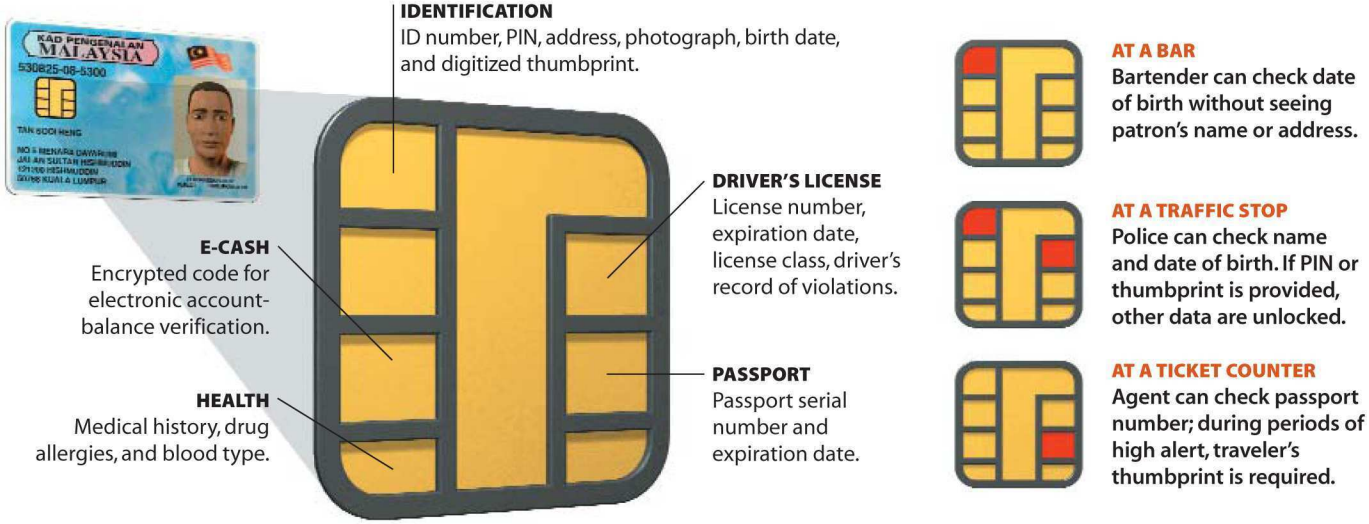
These networks of tiny cameras—and the host of other surveillance technologies that are now being unveiled—are both tributes to innovation and, as Wolf acknowledges, potential menaces to personal privacy. Indeed, the new marriage of ever smaller lenses and sensors, ever larger databases, and ever faster computers is making surveillance so cheap and commonplace that it is on the way to creating a state of nearly universal surveillance *(see "Surveillance Nation—Part One,"* TR *April 2003).*

In the past, government agencies and businesses have been blamed for the deployment of surveillance technology—and not without reason. In a single three-week period earlier this year, the Bush administration announced that it was building a system that pools real-time traffic data from Internet service providers and monitors threats to the global information network; inaugurated the Terrorist Threat Integration Center, a vast data bank that will combine domestic and foreign intelligence on U.S. citizens and foreign visitors; and opened up the State Department's database of 50 million visa applications to U.S. police departments. Meanwhile the mayor of London, England, launched a traffic control program that records the license plates of every vehicle entering the city center—and furnishes the information to intelligence agencies.

Such plans have met with scant citizen resistance—understandable, perhaps, given that these same citizens are installing nanny- and pet-watching cameras, flocking to automated highway-toll collection systems (which reduce lines as they record every car that passes through their gates), and scoping out prospective dates, friends, and employees using such Internet search engines as Google. Between 2000 and 2005, according to market research firm Frost and

A Smart Way to Protect Privacy

As this conceptual illustration shows, personal data on Malaysia's smart card chips—designed to replace driver's licenses—are stored in isolated files, each accessible only to authorized readers.



Watching What You Do

TECHNOLOGY	DESCRIPTION	SELECTED PROVIDERS
AT HOME		
"Nanny cams"	Small, easily hidden wireless digital video cameras for monitoring children and pets.	**Nanny Check**, Plainview, NY **Know Your Nanny**, North Brunswick, NJ
Infrared surveillance	Technology that alerts police to such suspicious thermal activity inside houses as the heat from marijuana-growing equipment.	**Monroe Infrared Technology**, Kennebunk, ME **Sierra Pacific**, Las Vegas, NV
ON THE ROAD		
Traffic cameras	Web cameras mounted at high-traffic points; specialized cameras that read plate numbers for law enforcement.	**Axis Communications**, Lund, Sweden **Computer Recognition Systems**, Cambridge, MA
Automobile transponders	Electronic toll deduction when users pass through tollgates; supported by laser vehicle measurement and axle number detection.	**Mark IV Industries**, Sölvesborg, Sweden **SAMSys Technologies**, Richmond Hill, Ontario
Cell phones	Technology that reports a cell phone user's precise location to authorities during 911 calls.	Mandatory for all U.S. wireless carriers and cell phone manufacturers by 2006
AT WORK		
Internet and e-mail monitoring	Text and data filters that ensure compliance with privacy and harassment laws and corporate confidentiality requirements.	**Tumbleweed Communications**, Redwood City, CA **Clearswift**, Theale, UK
Keystroke logging, file usage review	Systems that record everything typed into a computer, including e-mail, instant messages, and Web addresses.	**Amecisco**, San Francisco, CA **NetHunter Group**, Tallinn, Estonia
AT SCHOOL		
Web filtering	Software that prevents students from reaching inappropriate Web content.	**N2H2**, Seattle, WA **iTech**, Racine, WI
Locator wristbands	Bracelets that combine GPS and digital cell-phone signals to locate wearer within 30 meters.	**Wherify Wireless**, Redwood Shores, CA **Peace of Mind at Light Speed**, Westport, CT
AT THE STORE		
Smart cards	Microchips embedded in plastic cards that carry e-cash, along with driver's license, age and address information, and medical records.	**Gemplus**, Luxembourg **Oberthur Card Systems**, Paris, France
Supermarket discount cards	Cards—with embedded chips or standard magnetic stripe—that earn member discounts and track shopping habits.	**Catalina Marketing**, St. Petersburg, FL **SchlumbergerSema**, New York, NY

Sullivan, sales of digital video surveillance cameras will increase by a factor of 10. More and more of these cameras are being purchased by private associations, small businesses, and—most startling—consumers. CCS International, a surveillance products company in New Rochelle, NY, estimates that ordinary Americans are buying surveillance devices, many of dubious legality, at a clip of $6 million a *day*. We have met the enemy of our privacy, and it is us.

Although this technology is growing much faster than is generally recognized, its advance is neither inexorable nor uncontrollable. It will be constrained by the structure of the huge databases necessary to store and manipulate surveillance data—and by the cultural and legal environment in which those databases arise. In fact, the way databases are configured may help foster accountability and usage policies that could regulate the deployment of surveillance. Whether these tools are actually used, though, will depend on what citizens want and believe. In the United States, the rise of ubiquitous surveillance will be governed largely by the answer to the question first raised in the long-ago case of Charles Katz: What is a "reasonable expectation of privacy," anyway?

TAMING THE DATA TSUNAMI

One of the claimants to the title of the world's largest database sits on the edge of the Stanford University campus, connected to a three-kilometer-long particle accelerator. Housing records of the millions upon millions of elementary-particle interactions that occur in the accelerator, the BaBar database, as it is known, contains more than 680 terabytes of information—equivalent to a stack of copies of the Bill of Rights some 21,000 kilometers high. (A terabyte is 10^{12} bytes.) From a data-gathering viewpoint, the Stanford experiment is a nightmare. The accelerator smashes electrons and positrons into each other at almost the speed of light, creating an explosion of data in a few trillionths of a second—vastly more input than any computer network can handle. To make sense of these overwhelming infobursts, BaBar engineers have developed a variety of techniques for containing the flow of data. These techniques will almost certainly be used by the enormous surveillance archives of tomorrow, suggesting both how they will function and how—just possibly—they might be regulated for the public good.

Rather than trying to absorb the entire river of readings from the particle collisions, the sensors in the BaBar particle detector record just a few specific aspects of selected events, discarding millions of data points for every one kept. That small sip of raw data—about a gigabyte every few minutes of running time—is still too much for physicists to study, says Jacek Becla, the lead designer of the database. To further distill the observations, the detector's software intensively "preprocesses" the selected measurements, reducing each to a relative handful of carefully checked, easily manipulable numbers before incorporating them into the database.

Even after preprocessing, a data set can still be too big to examine efficiently in a single central locality. As a result, large databases often divide their work into smaller pieces and distribute the resulting tasks among hundreds or thousands of machines around a network. Many of these techniques were first implemented on a large scale by SETI@Home, a massively distributed system that hunts for alien civilizations. SETI@Home takes in radio telescope readings, breaks the data into chunks, and uses the Internet to dole them out to the home computers of more than four million volunteers. When these computers are otherwise idle, they run a screensaver-like program that probes the data for signs of sentient life.

As the extraordinary measures taken by BaBar and SETI@Home suggest, large databases face inherent problems. Simply running the routine comparisons that are intrinsic to databases takes much longer as data become more complex, says Piotr Indyk, a database researcher at MIT. Worse, he says, the results are often useless: as the data pool swells, the number of chance correlations rises even faster, flooding meaningful answers in a tsunami of logically valid but utterly useless solutions. Without preprocessing and distributed computing, the surveillance databases of tomorrow will drown in their own input.

It is, perhaps, unexpected that both preprocessing and distributed computing also exemplify ways the structure of databases might provide levers to control their use—if people want them. For privacy advocates, surveillance raises two critical issues: lack of accountability and the specter of information collected for a benign purpose being used for another, perhaps sinister, end. "Time and time again, people have misused this kind of data," says Peter G. Neumann, a computer scientist at SRI, a nonprofit research organization in Menlo Park, CA. To discover when users have overstepped or abused their privileges, he says, "accountability as to who is accessing what, altering what data, not updating stuff that should have been corrected, et cetera, is absolutely vital."

Such monitoring is already standard operating procedure in many large databases. SETI@home, for instance, tracks exactly which of its millions of member computers is examining which datum—not least because the system, according to Berkeley computer scientist David Anderson, its designer, sends dummy data to users during the 10 to 15 percent of the time it is down, and therefore needs to monitor what is real. Nonetheless, Neumann says, most commercial database programs don't securely record the usage data they collect. With off-the-shelf database software from Oracle, IBM, and Microsoft, he says, "there is no way" that such large surveillance databases as the Terrorist Threat Integration Center "could get accountability in any meaningful sense." The software simply allows for too many "trusted users"—people who have full access to the system and can modify audit trails, thus deleting their tracks from the logs. The possibility of meaningful accountability does exist—but people must demand it.

"IF THE POLICE CAN TRACK US AS WE GO ABOUT OUR DAILY ROUTINE, WE NEED TO BE ABLE TO SEE THE POLICE AS THEY GO ABOUT THEIRS. EQUAL ACCESS WOULD MAKE THEM A LOT MORE CAREFUL."

Similar logic applies to the fear that data collected for one purpose will be misused for another. Consider, for example, the program in London, England, that levies a £5 ($8) "congestion charge" on each vehicle crossing into the central city. To enforce collection, the city uses hundreds of digital video cameras and character recognition software to read the license plate of every vehicle crossing into the fee area. Plate numbers are matched against the list of drivers who have paid up; noncompliant vehicle owners receive summonses in the mail. Just before the program's launch, newspapers revealed that the images would be given to police and military databases, which will use face recognition software to scan for criminals and terrorists—an example of what privacy activists decry as "feature creep." Observes Marc Rotenberg, executive director of the Electronic Privacy Information Center in Washington, DC, "They say they're taking your picture to stop traffic jams. Then all of a sudden they're trying to find out if you're a terrorist."

As all this suggests, repurposing surveillance information is subject to so many pitfalls that "we need to build restrictions on the way data are used," says Lawrence Lessig, a Stanford University law professor who is the author of *Code and Other Laws of Cyberspace*. Ideally, in Lessig's view, "you'd want to have a situation like what goes on with credit reports—we can see them, and know something about who is using them and why, and potentially remove any errors."

The technology to provide such protections is already emerging. The Malaysian government is rolling out a multifunction smart card with 32 kilobytes of memory that can store up to seven types of data, including details about a person's identity, driver's license, bank account, and immigration status. Embedded software encrypts and compartmentalizes the information and keys it to the cardholder's biometric data, ensuring that when an authorized government or business official accesses one type of data, the other types remain off-limits *(see "A Smart Way to Protect Privacy," p. 48)*. If introduced into the United States, such cards could be set to tell bartenders that their bearers "are over 21 and can drink alcohol; but that's all," explains Lessig. "And if a police officer stops you, the card should only tell her that you have a valid driver's license"—and not, say, your Social Security number.

The same kinds of access controls should be applied to large, centralized



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databases, Lessig believes. Users logging onto a sensitive database should have to identify themselves, and their access should be restricted solely to data they are authorized to examine. To further deter misuse, the database should preserve a record of its users and their actions. Such precautions are not only technically feasible but, to Lessig's way of thinking, simply good policy. Still, he sees "next to no chance" that such precautions will be implemented, because terrorist attacks have changed the government's attitude toward privacy and because ordinary people have demonstrated their willingness to embrace the technology without understanding the consequences.

THE GOLDEN RULE OF SURVEILLANCE

Just hours after the first bombs fell on Afghanistan in October 2001, the Arabic television network Al-Jazeera broadcast a grainy videotape that showed Osama bin Laden reveling in the destruction of the World Trade Center. Partly because of the timing of the tape's release, the Internet was quickly filled with speculations that the tape and others that followed were counterfeited by bin Laden's confederates or the U.S. government. After all, video is easy to fake, isn't it?

Nonsense, says Steve Sullivan, R&D director for Industrial Light and Magic, the well-known digital-effects company. Such spoofing, he says, "is simply not possible with any techniques I'm aware of." Even for modest video quality, today's computational power and rendering skills fall far short of what would be required to model a human realistically enough to fool viewers. "You could hire an actor to impersonate [bin Laden], I suppose," Sullivan says. "Basically, though, when you see surveillance video, it's real."

Nonetheless, the impulse toward suspicion is fundamentally correct. Video may not yet be easily spoofed, but most other forms of digital data—spreadsheets, documents, and records of all types—are easy to alter subtly. "Sheer size and complexity are your enemy," says Bruce Schneier, chief technical officer for Counterpane Internet Security, in Cupertino, CA. "The vast majority of data stored or used by computers are never seen by people. Answers are assumed to be correct, but the integrity of every part of the system is nearly impossible to verify." In other words, even if original surveillance data are correctly observed and entered—far from a foregone conclusion—the deductions made by databases using such information must be treated with care.

Without safeguards, the security problems of large surveillance databases could quickly get out of hand. "It's like Willie Sutton," says Herbert Edelstein, president of Two Crows, a database consulting firm in Potomac, MD. "He said he broke into banks because that's where the money was. Well, identity thieves will try to break into large databases of personal information because that's where the identity data are." For similar reasons, any government database compiled for hunting criminals and terrorists will be irresistibly attractive to its own targets.

Unfortunately, computers are notoriously hard to secure, and this difficulty increases as they grow more numerous, complex, and heavily used. People were sharply reminded of this vulnerability on January 25, when the Slammer worm hit the Internet. (A worm is a malicious computer program that hijacks one computer after another, forcing each compromised machine to send out more identical worms.) Within 10 minutes of its appearance, Slammer had infected some 75,000 computers, many of them critically important to business. Alas, Slammer was not unique: almost every major site—from the *New York Times* to the CIA and FBI—has been cracked at one time or another. On the basis of a General Accounting Office analysis last year, Congressman Stephen Horn (R-CA) issued failing grades to 14 of the 24 major federal agencies on his annual "computer security report card" for Uncle Sam. Given such dismal statistics, operators of government, corporate, and other databases must assume their networks will be periodically compromised, and they should plan accordingly.

Yet this inescapable lack of trustworthiness—perhaps surprisingly—is not all bad. Indeed, the very need to be constantly suspicious of the integrity of large databases is a powerful argument for the accountability measures that would mitigate their impact on privacy.

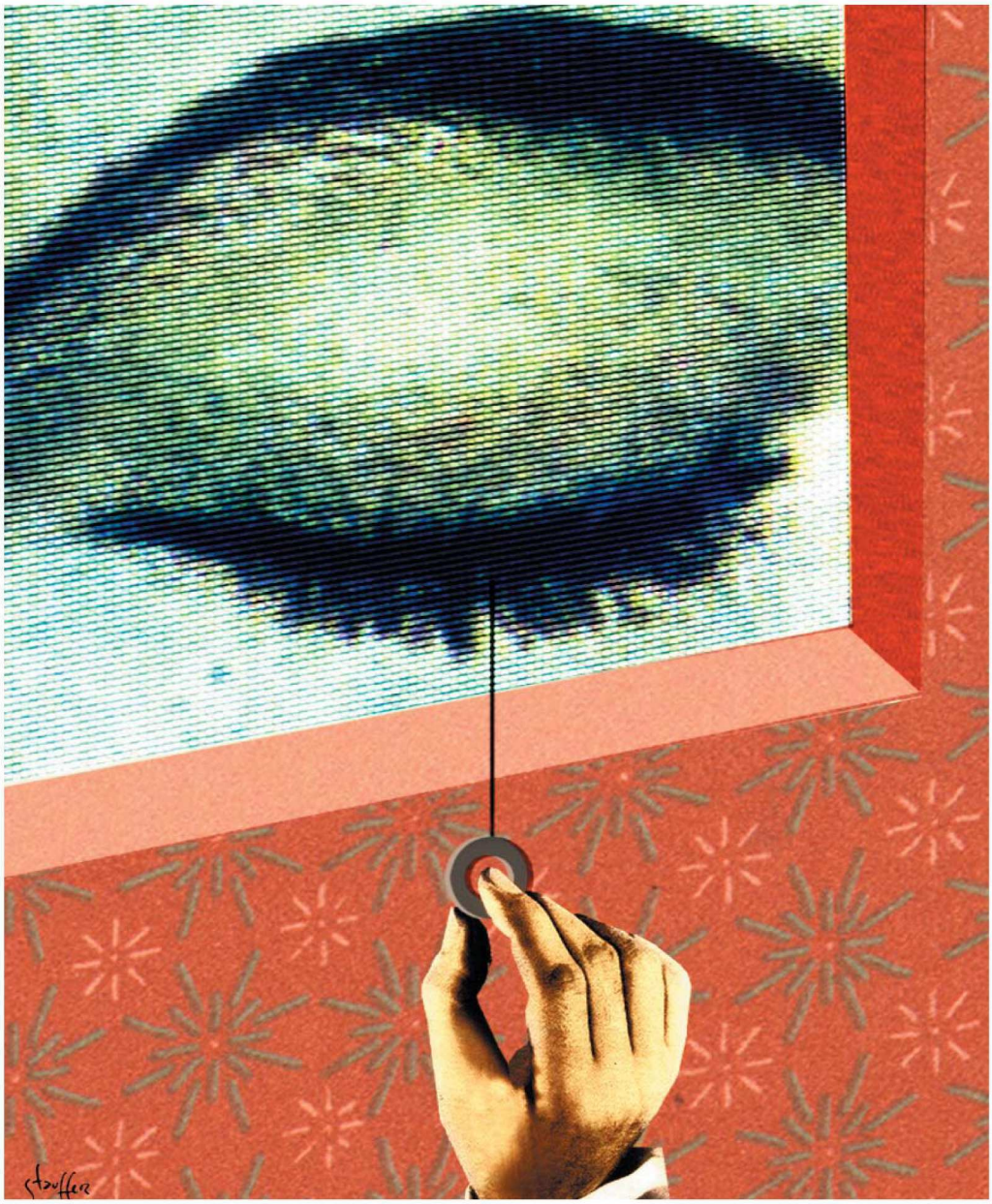
Stringent monitoring of database usage and public access to those records constitute what might be dubbed the Golden Rule of Surveillance. "If the police can track us as we go about our daily routine, we need to be able to see the police as they go about theirs," says Carl S. Kaplan, a New York City appellate lawyer and former *New York Times* columnist on Internet law. *(Kaplan conducted* TR*'s Point of Impact interview in this issue. See "Curbing Peer-to-Peer Piracy," p. 70.)* In his view, surveillance databases will be less prone to misuse if the same rules apply to everyone. "It's a fact of life that some police officers lie," he says. "Equal access would either make it a lot harder for them to lie or make them a lot more careful about what surveillance they use."

THE ELECTRONIC PANOPTICON

In 1791 the British philosopher Jeremy Bentham envisioned a "panopticon," a domelike prison where guards could observe all the inmates at all times from within a central observation tower. Bentham never managed to convince the Crown to build his prison, but its principles were embraced across the Atlantic, in Philadelphia's Eastern State Penitentiary. Built in 1829, this radical building became a global sensation—the most influential prison ever built, according to Max Page, an architectural historian at the University of Massachusetts, Amherst.

In the Philadelphia panopticon, prisoners lived in solitary confinement in seven cellblocks that radiated like the spokes of a wheel from an observation room. The inmates could see neither the guards watching them nor the other prisoners around them; their only window was a skylight. Living in isolation under the scrutiny of invisible authorities, inmates were supposed to reflect on their sins and become penitent: Eastern State was the world's first "penitentiary."

LEGISLATURES COULD DEMAND THAT ORGANIZATIONS KEEP DETAILED PUBLICLY AVAILABLE RECORDS OF HOW THEIR DATABASES ARE USED. BUT THAT WILL NOT HAPPEN WITHOUT A SHIFT IN PUBLIC OPINION.



After Eastern State was unveiled, governments around the world built more than 300 panopticon prisons. But they gradually fell out of use, partly because neither wardens nor inmates could bear playing their roles. According to Dutch architect Rem Koolhaas's study of panopticons, prisoners found ways to avoid surveillance; guards, disheartened by the lack of interaction, left the center. Ultimately, inmates and guards found themselves continuously watching each other, transforming the prison, in Koolhaas's phrase, into "a transparent space" where "no action or inaction remains unnoticed."

Similarly, omnipresent electronic surveillance leads to what Carl Botan, a researcher at Purdue University's Center for Education and Research in Information Assurance and Security, calls panoptic effects—unexpected reactions that counter the purpose of monitoring. According to the American Management Association, nearly 80 percent of major U.S. companies electronically monitor their employees. Common observational methods include logging telephone calls and e-mail to determine which employees are wasting time and periodically recording what is on workers' computer screens to inhibit porn perusing. Such innovations, Botan says, do help employers encourage efficiency and avoid "hostile environment" litigation. But there are other, unintended results. "Employees who know everything is being logged," he says, "are less willing to exchange information with other employees—the horizontal communication that is the problem-solving communication in the workplace. Not wanting to be recorded calling home to monitor how a sick kid is doing, they'll take a sick day instead." If people aren't comfortable with a surveillance regime, Botan argues, they subvert it, exacerbating the problem surveillance was supposed to ameliorate.

Panoptic effects take hold in the larger society as surveillance spreads, says Jeffrey Smith, a lawyer at Arnold and Porter in Washington, DC, who was general counsel to the Central Intelligence Agency. "The notion of what is private and what the limits of privacy are clearly changes to reflect technology," he says. "If what was once thought of as public data can be used to construct what might be an intrusively detailed picture of your life, people will push back. The courts will visit this issue. There will be legislation too."

Much as last year's accounting scandals led Congress to push for corporate reforms, legislatures could demand that organizations that maintain databases of personal information keep detailed publicly available records of their use. But that will not happen without a shift in public opinion. "A lot of law turns on 'reasonable expectation of privacy,'" says Paul Schwartz, a privacy law specialist at Brooklyn Law School. "But as technology becomes cheaper and surveillance spreads everywhere, the danger is that the reasonable expectation of privacy will change." If Americans grow accustomed to a lack of privacy, in other words, they will get exactly what they expect.

"This technology could do a lot of good and a lot of harm," says Shari Pfleeger, a computer scientist and senior researcher at the RAND think tank in Washington, DC. "But to get the balance right, it needs to be actively talked about." More often than is commonly realized, such public discussion—nudged along by legal action and ongoing public-awareness campaigns—has transformed prevailing notions of acceptable behavior. Examples include the dramatic turnabouts over the past two decades in attitudes toward smoking and drunk driving, both of which were driven in part by grass-roots activism. The rapidity of the advances in surveillance technology, unfortunately, means that society has much less time to confront the trade-offs between security and privacy. The moment for debate and conversation is now, while the technology is still in its adolescence. TR

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May 13, 2003

RECEPTION & DINNER
Museum of Science
6:30 P.M. – 10:30 P.M.

Dinner Keynote Address
His Excellency Mitt Romney
Governor, Commonwealth of Massachusetts

May 14, 2003

SYMPOSIUM
Massachusetts Institute of Technology
7:30 A.M. – 5:30 P.M.

Keynote Address
Professor Charles Fine,
Author of *Clockspeed*
Chrysler Leaders for Manufacturing Professor
MIT Sloan School of Management

MIT $50K ENTREPRENEURSHIP COMPETITION AWARDS CEREMONY
Invitation extended to IdeaStream attendees
7:00 P.M. – 9:00 P.M.

More than 100 national patent processes confront inventors in today's global economy. Will the U.S. meet the world halfway to craft a unified system?

BY EVAN I. SCHWARTZ

PATENTS GO GLOBAL

On May 23, 1997, Atlanta inventor Clyde Bryant filed for a U.S. patent on his conception of an improved internal combustion engine. In written descriptions of 26 claims and in 34 pages of diagrams, he disclosed an auto engine that aims not only to burn fuel more cleanly but also to deliver greater torque and higher fuel efficiency than a standard engine. Bryant had already started a company, Entec Engine, to develop the technology, and the business's entire future was wrapped up in this patent application. The process was straightforward enough, costing less than $10,000 in filing fees and legal expenses. But Bryant was immediately confronted with an unavoidable conundrum: because of the global nature of the auto industry, unless he protected his invention worldwide, someone else would be able to patent and market the engine in another country. "The only way to do it was to file everywhere at once," he says.

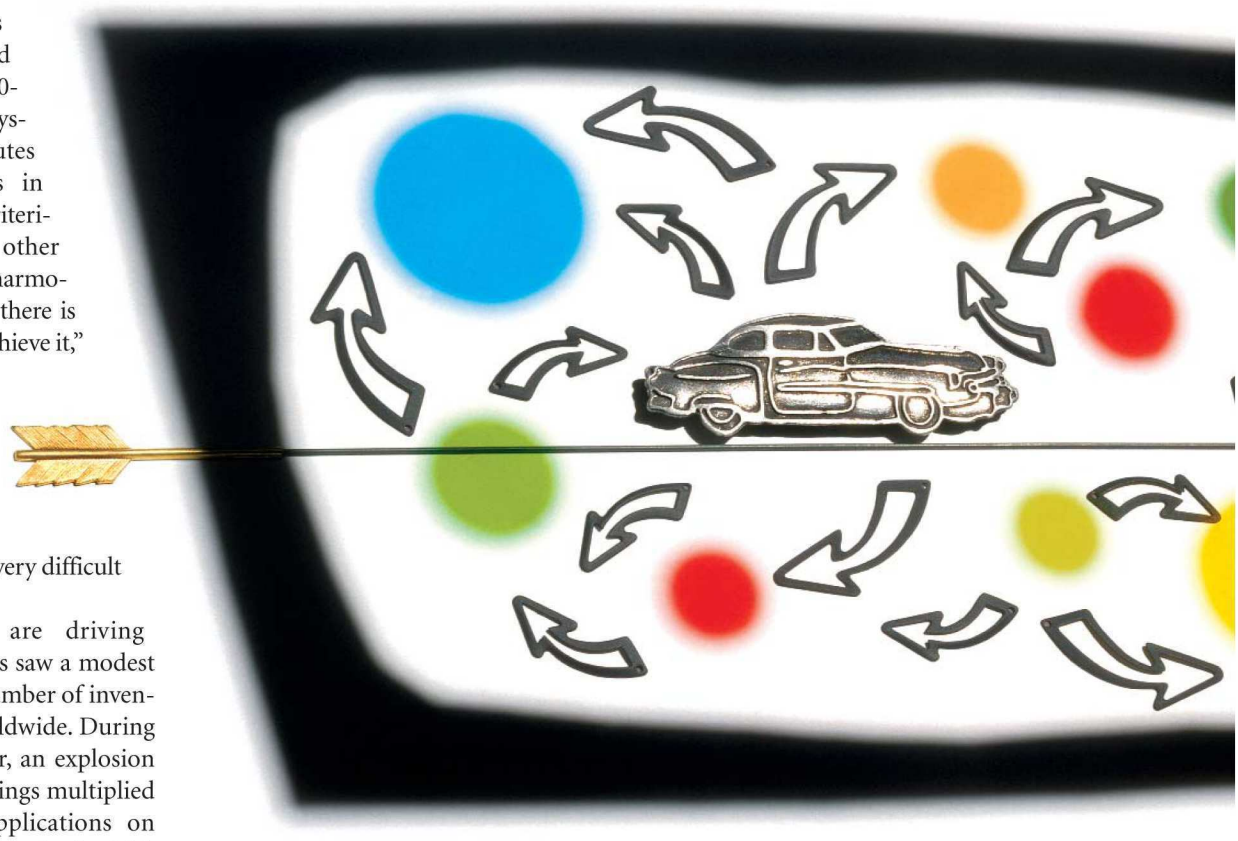
Bryant's Entec is one of an increasing number of companies stepping into the international patent jungle, where 120 national patent systems challenge inventors with opposing philosophies and examination rules, not to mention translation requirements and separate filing fees. Working with an Atlanta law firm that has an office in Munich, Germany, Bryant learned that failure to file in certain foreign countries soon would result in forfeiting his rights forever. "It's a lot of work to redo the claims for many of these countries," he says.

But over the next few months, the law firm churned out applications for Russia, Ukraine, Georgia, Australia, and Singapore. Through the European Patent Office, Bryant filed an application that would protect his invention in 23 other countries. The cost of all the applications: $78,000 plus a whopping $200,000 in legal fees. When his U.S. patent, number 6,279,550, was issued in August 2001, Bryant rejoiced, but when his European application was granted in November 2002, he learned it would cost almost $7,000 more per country to take the final step of actually getting the patents issued. To pay the tabs, Bryant's startup gave equity to the law firm.

The creation of a single global patent system could solve this conundrum for Bryant and other small inventors. Even multinational corporations that can afford to file everywhere are pushing for "deep harmonization," an international initiative aimed at forging a global patent. But in return for eliminating duplicate filing fees, most issuance costs, and translation requirements, such an effort will likely entail stark trade-offs for innovators worldwide.

Even as *Technology Review*'s annual Patent Scorecard *(p. 59)* tracks the number and strength of U.S. patents won by 150 companies in eight high-tech sectors, harmonization looms as a watchword. Harmonization means imposing a single set of global rules and depends on coming up with one answer to a contro-

versial question: what is patentable? U.S. inventors in particular may be forced to abandon America's 200-year-old first-to-invent system of settling disputes between rival inventors in favor of the first-to-file criterion that guides most other nations. "The goal [of harmonization] is brilliant, and there is tremendous pressure to achieve it," says Joanne Hayes-Rines, publisher of *Inventors' Digest*, the official publication of the United Inventors Association of the USA. "But it's going to be very difficult to get there."



Global economics are driving harmonization. The 1990s saw a modest 27 percent jump in the number of inventions seeking patents worldwide. During the same period, however, an explosion of country-by-country filings multiplied the total number of applications on those same inventions nearly fivefold, according to the World Intellectual Property Organization, the umbrella association overseeing the harmonization negotiations. "It's a measure of globalization," says Francis Gurry, assistant director general of the organization. About 90 percent of the seven million-plus patent applications filed worldwide each year are filings in more than one country for the same invention, he says. Reducing that number will require forging not only a better global filing system but also a common examination process. The trick, he says, will be getting the big three—the U.S. Patent and Trademark Office, the European Patent Office, and the Japanese Patent Office—"to achieve agreement on the fundamentals of patent law."

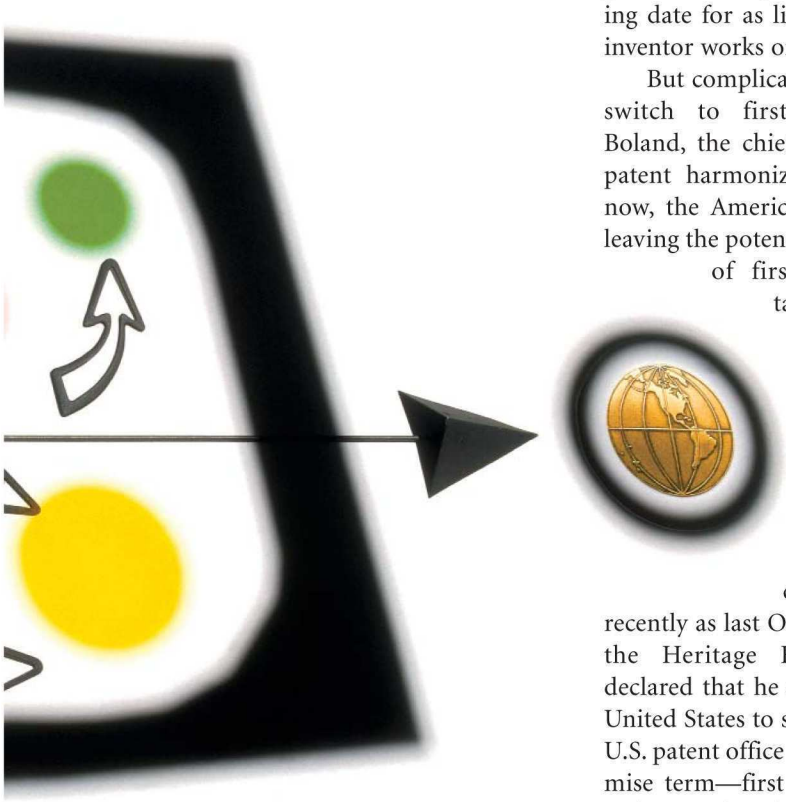
The U.S. patent system, however, sharply conflicts with other systems. Whereas all other countries grant a patent to the party who is first to file an application, the United States maintains an elaborate legal process for sorting out the precedence of rival inventors—regardless of their filing dates. A 1989 effort to develop a single, worldwide patent system convinced Canada to switch to first-to-file, but treaty negotiations broke down when the United States refused to compromise on this point, mainly because of intense resistance from independent inventors who say it gives the upper hand to big corporations with the resources to file quickly and prolifically. The European "first-to-file system is simple, but sometimes it isn't fair," admits Barbara Cookson, a partner at Nabarro Nathanson, a London-based law firm. "The U.S. system aims to be fair but at a tremendous cost." That's because patent interference suits that aim to resolve competing claims between parties can involve trotting out strings of witnesses and evidence such as notarized lab books and prototypes. Proving who actually invented first can take years and cost millions of dollars.

The debate is charged with emotion. The ability to sort out rival claims is "the only piece of armor" a small business has when it's up against a big corporation that files patents early and often, says Don Costar, founder of the Nevada Inventors Association. According to many U.S. inventors, the first patent law signed by President George Washington in 1790 is clear on the point. Costar believes the principle is embedded even in the Constitution. The drafters "wrote the laws directly opposite to what was happening in England," he says. "They saw that the inventor may be lying in the ditch with his throat cut, while the guy who filed it with the king got all the benefits and riches."

Many large corporations, on the other hand, are willing to make the switch. "As a worldwide company, we favor harmonization," says Fred Boehm, IBM's assistant general counsel. "It would eliminate the interference problem in the U.S., and we've been involved in a number of those cases." He'd like to see the United States trade away first-to-invent in return for other countries' adopting America's one-year grace period before filing. The grace period allows U.S. inventors to publish papers and speak publicly about their creations without undermining their patent rights. In much of the rest of the world, such activities kill eligibility. Inventors outside the United States "have to operate in total secrecy," says Hayes-Rines.

This historic move is considered likely by those involved in the process. "The first-to-invent issue is passé," says

PIERRE-YVES GOAVEC



provides a simple way to lock in a filing date for as little as $80 while the inventor works on a full application.

But complications in realizing the switch to first-to-file lurk. Lois Boland, the chief U.S. negotiator on patent harmonization, says that for now, the American strategy calls for leaving the potentially disruptive issue of first-to-invent off the table in Geneva, so as not to rile the passions of independent inventors in the United States. Meanwhile, the current director of the patent office, James E. Rogan, is coy on the matter. As recently as last October in a speech to the Heritage Foundation, Rogan declared that he sees no need for the United States to switch. Currently, the U.S. patent office is floating a compromise term—first inventor to file—in order to dispel the notion that it would be common for a noninventor to rip off an idea and beat the real inventor to the patent office.

A UNIFIED GLOBAL PATENT SYSTEM COULD SAVE BILLIONS OF DOLLARS. "THE GOAL IS BRILLIANT. BUT IT'S GOING TO BE VERY DIFFICULT TO GET THERE."

Q. Todd Dickinson, director of the U.S. Patent and Trademark Office under President Clinton. Dickinson now represents the American Bar Association in patent harmonization talks held every six months by the World Intellectual Property Organization in Geneva. Despite the fact that the bar association itself is divided on the issue, "I think we can sell first-to-file" to the American public, Dickinson says. "A working assumption in Geneva is that the U.S. will have to come around on this issue at the end of the day." Independent inventors, he says, now have fewer excuses for not filing right away. The Internet provides abundant resources, including the ability to file online, and a one-year provisional application for patent filings, which was introduced in 1995,

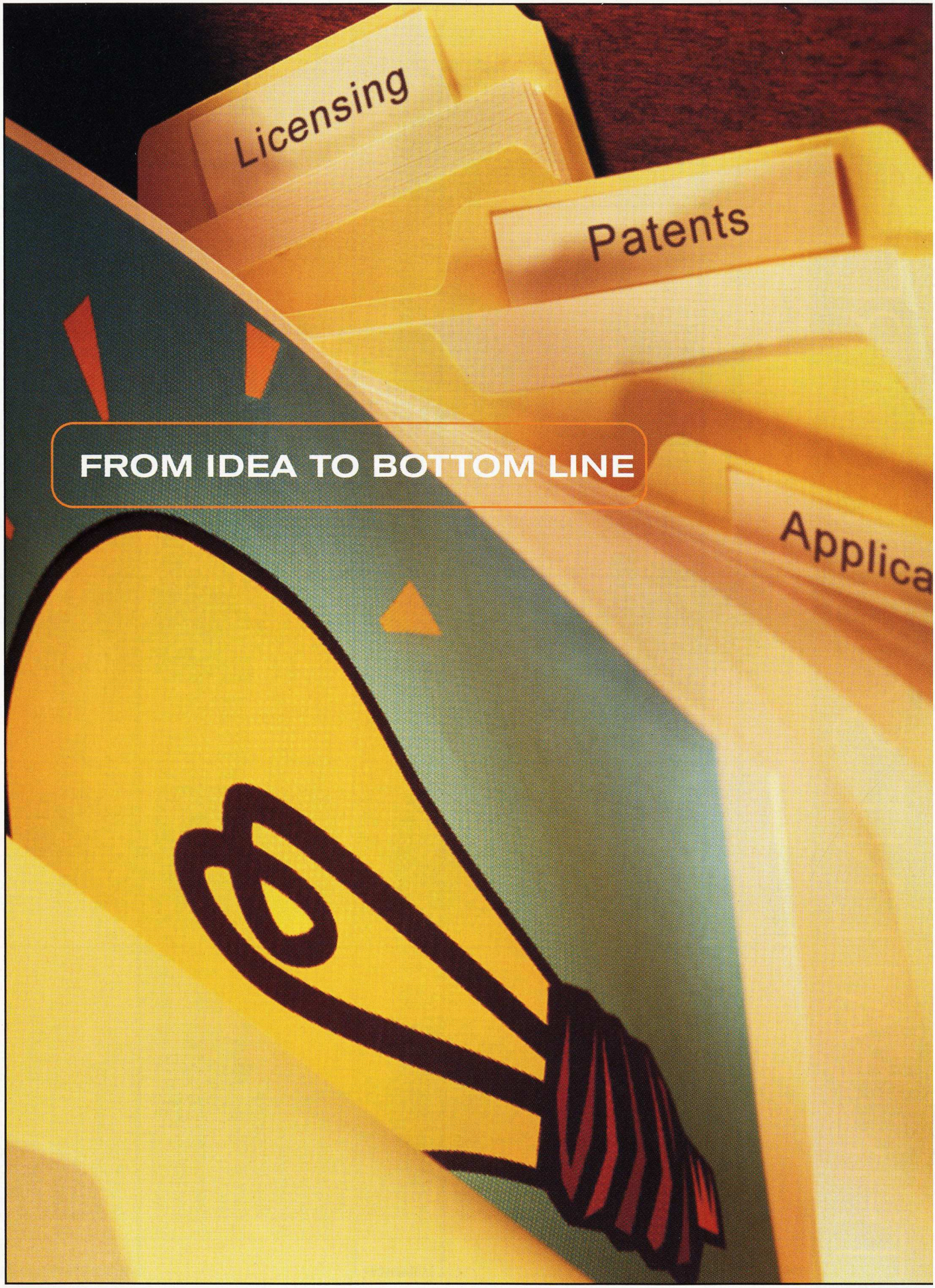
Other issues now on the table may be even more difficult to handle. Foremost among them is the definition of "patentable subject matter," in other words, reaching universal agreement on what may be patented, a topic of vigorous debate. "The U.S. says that everything under the sun is patentable," says the World Intellectual Property Organization's Gurry. Almost every other country, he adds, disagrees. Among the most contentious subjects are business method patents. The United States typically, and somewhat notoriously, allows patents for business practices such as Amazon.com's single-click Internet shopping, which allows its customers to save their shipping and payment information so they can buy books and other items simply by clicking once on an icon.

The United States is also the most generous in granting patents for software and genetic discoveries and treatments. Much of the rest of the world holds "a different view," according to Boland, favoring what's known as a technical-effect requirement to weed out ideas that have no technological component.

At the same time, a rift has opened between industrial and developing countries over patents on medicinal plants and other biological resources. Latin American and African nations favor rules requiring that foreign companies seek consent to remove such resources or be forbidden from receiving patents on them. Such rules would replace today's patchwork of regulations, none of which prevent such patents. Supporters of that idea also back a requirement for citing the country of origin in any patent application. "There is absolutely no agreement on this," says Gurry.

With so much open debate, officials involved in the negotiations don't expect a document aimed at deep harmonization to be ready before the fall of 2004. Any global patent treaty would have to be ratified by Congress, and with no specific proposal on the table, it's premature to guess whether ratification is likely.

In the meantime, the costs and confusion caused by differences in national patent systems continue to escalate. Boehm says IBM currently spends upwards of $200 million per year on its intellectual-property protection efforts, and redundant country-by-country patent applications comprise a large part of that expense. Independent inventors seldom file global applications at all, says Costar. "When they find out the cost, they drop the idea." As for Entec's engine, Clyde Bryant says his company is negotiating with DaimlerChrysler and a number of other manufacturers over licenses for his technology. Although the price was steep, he says he is relieved to have worldwide protection: the talks with the German auto giant are taking place not in Detroit, but in Stuttgart.


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THE PATENT SCORECARD 2003

		TECHNOLOGICAL STRENGTH/RANK		NUMBER OF PATENTS		CURRENT-IMPACT INDEX		SCIENCE LINKAGE		TECHNOLOGY CYCLE TIME	
	COMPANY[1]	2002	1997–2001 AVERAGE[2]	2002	1997–2001 AVERAGE[2]	2002	1997–2001 AVERAGE[2]	2002	1997–2001 AVERAGE[2]	2002	1997–2001 AVERAGE[2]
AEROSPACE	**Northrop Grumman** (U.S.)	401/1	173/4	441	228	0.91	0.76	0.55	0.63	8.3	9.0
	Lockheed Martin (U.S.)	340/2	300/1	309	315	1.10	0.95	1.75	2.01	8.5	8.7
	United Technologies (U.S.)	258/3	219/2	318	342	0.81	0.64	0.27	0.38	10.9	10.5
	Boeing (U.S.)	159/4	203/3	224	257	0.71	0.79	0.41	0.68	11.8	12.5
	Rockwell Automation (U.S.)	111/5	147/5	105	148	1.06	0.99	0.50	0.57	6.5	7.7
	Rockwell Collins (U.S.)	92/6	55/9	84	33	1.10	1.66	0.33	0.66	6.9	5.9
	BAE Systems (U.K.)	87/7	19/12	124	35	0.70	0.54	0.26	0.40	10.3	11.3
	Thales (France)	78/8	98/6	111	122	0.70	0.80	0.30	0.62	7.8	8.6
	EADS (Netherlands)	72/9	69/7	131	132	0.55	0.52	0.34	0.36	10.8	11.7
	Textron (U.S.)	70/10	56/8	90	71	0.78	0.79	0.74	0.12	12.1	11.4
	GKN (U.K.)	30/11	26/11	46	38	0.65	0.69	0.45	0.08	9.6	10.1
	General Dynamics (U.S.)	27/12	31/10	28	34	0.95	0.92	1.32	3.24	11.2	10.4
AUTOMOTIVE	**Delphi Automotive Systems** (U.S.)	903/1	196/12	654	183	1.38	1.07	0.19	0.24	7.1	6.8
	Honda (Japan)	731/2	505/4	703	476	1.04	1.06	0.02	0.13	7.4	7.0
	Bosch (Germany)	672/3	522/2	800	600	0.84	0.87	0.11	0.18	8.0	7.9
	Denso (Japan)	629/4	503/5	557	458	1.13	1.10	0.12	0.24	6.7	6.9
	Toyota Motor (Japan)	540/5	507/3	380	409	1.42	1.24	0.41	0.35	5.3	6.0
	Ford Motor (U.S.)	511/6	400/7	433	404	1.18	0.99	0.44	0.34	6.4	8.2
	DaimlerChrysler (Germany)	508/7	572/1	546	590	0.93	0.97	0.12	0.22	8.4	8.9
	General Motors (U.S.)	417/8	502/6	353	469	1.18	1.07	0.53	0.62	6.7	7.5
	Nissan Motor (Japan)	385/9	272/8	292	249	1.32	1.09	0.08	0.09	5.4	6.3
	Yazaki (Japan)	274/10	272/8	334	299	0.82	0.91	0.05	0.02	7.3	6.7
	TRW (U.S.)	260/11	223/10	190	155	1.37	1.44	0.06	0.08	6.1	6.7
	Magma International (Canada)	247/12	146/13	106	90	2.33	1.62	0.50	0.66	9.7	11.1
	Aisin Seiki (Japan)	245/13	222/11	180	183	1.36	1.21	0.05	0.46	5.0	6.4
	Visteon (U.S.)	220/14	53/14	202	53	1.09	1.00	0.04	0.08	8.0	8.8
BIOTECHNOLOGY/PHARMACEUTICALS	**Maxygen** (U.S.)	434/1	45/18	35	4	12.39	11.96	111.40	118.53	4.3	3.7
	Caliper Technologies (U.S.)	404/2	84/14	50	15	8.09	5.54	12.46	12.18	5.8	5.1
	Symyx Technologies (U.S.)	292/3	9/27	47	7	6.21	1.34	21.70	12.35	8.1	7.5
	Diversa (U.S.)	245/4	35/22	17	8	14.43	4.37	13.58	5.45	4.8	3.9
	Pfizer (U.S.)	188/5	163/4	285	239	0.66	0.68	7.40	6.47	8.8	9.4
	Affymetrix (U.S.)	168/6	75/15	50	22	3.37	3.33	88.20	25.06	10.8	8.1
	Guilford Pharmaceuticals (U.S.)	166/7	30/24	40	18	4.15	1.69	62.65	39.10	9.1	8.2
	GlaxoSmithKline (U.K.)	140/8	185/3	292	319	0.48	0.58	6.30	5.58	7.5	8.7
	Aventis (France)	123/9	227/1	316	494	0.39	0.46	11.70	7.91	9.1	9.6
	Merck (U.S.)	115/10	187/2	234	256	0.49	0.73	14.50	11.19	6.7	6.5
	Pharmacia (U.S.)	114/11	92/13	196	177	0.58	0.52	17.60	13.59	10.8	9.6
	F. Hoffmann-La Roche[3] (Switzerland)	110/12	153/5	229	242	0.48	0.63	6.75	7.65	8.4	9.0
	Bristol-Myers Squibb (U.S.)	95/13	139/6	154	178	0.62	0.78	11.93	14.10	8.6	8.6
	Abbott Laboratories (U.S.)	91/14	124/9	138	172	0.66	0.72	6.92	7.03	8.3	9.6
	Isis Pharmaceuticals (U.S.)	82/15	107/10	111	77	0.74	1.39	32.15	32.79	7.3	6.6
	Schering (Germany)	74/16	94/12	77	96	0.96	0.98	5.90	6.08	8.7	8.5
	Emisphere Technologies (U.S.)	74/16	31/23	14	10	5.29	3.18	85.57	146.53	12.8	12.9
	Genzyme (U.S.)	66/18	41/19	47	40	1.40	1.04	15.74	19.66	8.7	9.0
	AstraZeneca (U.K.)	65/19	97/11	141	195	0.46	0.50	6.04	6.98	8.4	8.6
	Eli Lilly (U.S.)	64/20	130/7	125	185	0.51	0.70	6.00	8.86	10.3	8.5
	Novartis[4] (Switzerland)	61/21	129/8	129	235	0.47	0.55	8.67	9.76	10.4	9.4
	Nektar Therapeutic[5] (U.S.)	56/22	13/26	19	9	2.93	1.37	8.84	7.20	8.9	9.7
	Schering-Plough (U.S.)	53/23	67/16	81	90	0.66	0.74	14.58	12.73	5.9	8.7
	Boehringer-Ingelheim (Germany)	49/24	39/21	101	66	0.49	0.59	6.65	8.05	8.7	8.5
	Nanogen (U.S.)	48/25	40/20	10	7	4.83	5.54	16.10	14.06	9.4	8.5
	Wyeth (U.S.)	44/26	56/17	84	93	0.52	0.61	15.72	10.46	8.6	8.2
	Ligand Pharmaceuticals (U.S.)	43/27	16/25	24	16	1.81	0.95	28.62	21.00	7.6	7.8
CHEMICALS	**3M** (U.S.)	722/1	642/2	564	522	1.28	1.23	2.80	2.46	11.8	10.8
	Procter and Gamble (U.S.)	582/2	702/1	441	478	1.32	1.47	1.92	1.77	9.8	10.7
	BASF (Germany)	300/3	297/4	626	646	0.48	0.46	1.49	2.07	11.1	10.3
	Bayer (Germany)	298/4	275/5	620	612	0.48	0.45	2.65	3.21	10.8	9.7
	Bridgestone (Japan)	226/5	136/8	193	170	1.17	0.80	0.71	0.72	9.5	10.0
	DuPont (U.S.)	221/6	320/3	401	478	0.55	0.67	5.60	4.60	10.4	10.9
	Cabot (U.S.)	185/7	83/13	56	28	3.30	2.99	3.53	4.88	12.6	10.9
	Shin-Etsu Chemical (Japan)	166/8	134/9	213	200	0.78	0.67	0.60	0.49	6.5	7.4
	Dow Chemical (U.S.)	160/9	202/6	213	258	0.75	0.78	4.72	4.44	11.3	10.4
	Goodyear Tire and Rubber (U.S.)	154/10	70/14	195	105	0.79	0.67	0.13	0.16	13.4	12.5
	Henkel (Germany)	144/11	97/12	141	171	1.02	0.57	0.44	1.17	11.8	11.9
	E.ON Energie (Germany)	132/12	112/10	235	229	0.56	0.49	1.20	0.96	10.4	10.1
	Toyoda Gosei (Japan)	115/13	69/15	88	63	1.31	1.09	0.90	0.24	6.9	6.7
	SpeedFam-IPEC (U.S.)	111/14	61/17	33	21	3.35	2.86	0.12	0.33	5.5	5.6
	Rohm and Haas (U.S.)	107/15	175/7	147	174	0.73	1.01	0.77	0.85	9.4	8.4
	Sumitomo Rubber (Japan)	107/15	63/16	89	75	1.20	0.84	0.02	0.04	6.8	7.9
	Continental (Germany)	106/17	49/18	120	69	0.88	0.71	0.17	0.65	7.8	8.5
	L'Air Liquide (France)	96/18	98/11	130	117	0.74	0.84	0.77	0.88	10.3	9.8
COMPUTERS	**IBM** (U.S.)	5,668/1	5,535/1	3,334	2,727	1.70	2.03	0.78	1.10	5.3	5.7
	Hewlett-Packard (U.S.)	2,240/2	2,502/2	1,391	1,226	1.61	2.04	0.69	1.05	5.7	5.8
	NEC (Japan)	1,824/3	2,093/3	1,920	1,789	0.95	1.17	0.55	0.72	4.8	4.9
	Fujitsu (Japan)	1,601/4	1,515/4	1,368	1,193	1.17	1.27	0.58	0.59	5.7	5.7
	Microsoft (U.S.)	1,385/5	1,078/5	515	342	2.69	3.15	2.97	2.68	4.7	4.5
	Sun Microsystems (U.S.)	1,060/6	1,048/6	505	411	2.10	2.55	2.31	2.06	5.3	4.7
	Xerox (U.S.)	863/7	910/7	702	669	1.23	1.36	0.89	1.05	7.6	6.8
	Cisco Systems (U.S.)	800/8	427/11	234	86	3.42	4.96	2.22	1.46	6.3	5.9
	Seiko Epson (Japan)	753/9	514/8	633	357	1.19	1.44	0.57	0.92	6.1	7.3

Hon Hai (Taiwan)	739/10	432/10	432	209	1.71	2.07	0.00	0.00	3.5	4.3
Seagate Technology (U.S.)	495/11	344/14	344	218	1.44	1.58	1.02	0.92	6.5	6.6
3Com (U.S.)	475/12	361/13	198	116	2.40	3.10	0.54	0.50	5.5	4.9
Oki Electric (Japan)	357/13	257/16	361	224	0.99	1.15	0.31	0.44	5.1	5.2
Ricoh (Japan)	319/14	487/9	351	412	0.91	1.18	0.35	0.33	5.3	6.0
Silverbrook Research (Australia)	312/15	86/22	121	25	2.58	3.42	0.05	0.16	4.6	4.0
EMC (U.S.)	251/16	213/18	103	73	2.44	2.93	1.13	1.70	5.4	5.4
Dell Computer (U.S.)	226/17	300/15	108	104	2.09	2.90	0.12	0.07	5.4	5.0
NCR (U.S.)	225/18	248/17	161	153	1.40	1.62	0.62	0.76	7.2	6.7
Oracle (U.S.)	213/19	159/21	86	59	2.48	2.67	2.36	1.38	4.0	3.8
Unisys (U.S.)	188/20	161/20	119	106	1.58	1.52	0.42	0.63	4.7	6.1
Digimarc (U.S.)	166/21	65/23	28	7	5.93	8.84	29.35	29.24	8.9	7.8
International Game Technology (U.S.)	142/22	40/24	45	13	3.16	2.96	0.08	0.01	5.0	7.1
Immersion (U.S.)	137/23	193/19	21	18	6.53	10.51	25.09	23.47	7.5	6.6
Apple Computer (U.S.)	130/24	408/12	77	166	1.69	2.45	1.58	1.29	5.6	5.4
ELECTRICAL/ELECTRONICS										
Hitachi (Japan)	2,390/1	1,662/2	1,882	1,340	1.27	1.24	0.61	0.73	6.7	6.7
Canon (Japan)	1,840/2	1,950/1	1,937	1,823	0.95	1.07	0.47	0.55	7.3	7.7
General Electric (U.S.)	1,832/3	697/11	1,681	860	1.09	0.81	6.11	0.61	10.0	9.9
Matsushita Electric (Japan)	1,678/4	1,410/6	1,712	1,294	0.98	1.09	0.45	0.57	6.0	6.0
Toshiba (Japan)	1,636/5	1,585/5	1,352	1,248	1.21	1.27	0.49	0.61	5.6	5.9
Mitsubishi Electric (Japan)	1,607/6	1,245/7	1,474	1,112	1.09	1.12	0.40	0.60	5.3	5.9
Sony (Japan)	1,553/7	1,600/3	1,601	1,322	0.97	1.21	0.46	0.39	5.6	5.6
Samsung (South Korea)	1,485/8	1,597/4	1,563	1,452	0.95	1.10	0.24	0.19	5.2	5.5
Koninklijke Philips Electronics (Netherlands)	1,238/9	1,034/9	1,276	975	0.97	1.06	0.57	0.62	5.6	6.0
Siemens (Germany)	1,221/10	1,105/8	1,357	1,242	0.90	0.89	0.55	0.94	7.3	7.2
Sharp (Japan)	695/11	667/12	626	575	1.11	1.16	0.70	0.83	5.3	5.3
Eastman Kodak (U.S.)	558/12	826/10	706	908	0.79	0.91	0.36	0.35	8.3	8.2
Tokyo Electron (Japan)	462/13	325/14	250	150	1.85	2.17	0.44	0.34	5.5	6.1
Agilent Technologies (U.S.)	428/14	147/19	327	103	1.31	1.42	1.08	2.11	6.1	6.6
Tyco International (Bermuda)	409/15	624/13	356	499	1.15	1.25	0.48	0.70	9.9	9.8
Murata (Japan)	403/16	237/15	443	252	0.91	0.94	0.18	0.25	6.5	7.4
Sanyo Electric (Japan)	302/17	234/17	378	244	0.80	0.96	0.26	0.46	5.3	5.9
LG Electronics (South Korea)	296/18	236/16	384	281	0.77	0.84	0.14	0.20	5.0	5.5
Emerson Electric (U.S.)	248/19	170/18	197	200	1.26	0.85	2.08	1.45	9.9	10.6
LG Philips LCD (South Korea)	222/20	34/20	149	16	1.49	2.10	1.65	2.14	4.9	4.6
SEMICONDUCTORS										
Micron Technology (U.S.)	3,943/1	2,813/1	1,851	1,078	2.13	2.61	2.65	1.86	6.5	5.6
Advanced Micro Devices (U.S.)	1,993/2	1,672/3	1,152	760	1.73	2.20	0.53	0.92	4.4	4.8
Intel (U.S.)	1,893/3	1,720/2	1,088	714	1.74	2.41	0.74	0.93	5.0	5.2
Applied Materials (U.S.)	1,334/4	695/6	517	295	2.58	2.36	1.62	1.65	7.4	7.2
Texas Instruments (U.S.)	1,056/5	1,100/4	744	705	1.42	1.56	0.85	1.32	6.4	6.6
Semiconductor Energy Laboratory (Japan)	840/6	449/11	253	159	3.32	2.83	3.28	2.79	6.7	6.3
Taiwan Semiconductor (Taiwan)	823/7	879/5	465	363	1.77	2.42	0.19	0.24	4.2	4.0
Hynix Semiconductor (South Korea)	599/8	676/8	599	524	1.00	1.29	0.47	0.37	4.8	5.0
LSI Logic (U.S.)	562/9	691/7	309	303	1.82	2.28	0.90	1.34	5.3	5.5
Infineon Technologies (Germany)	521/10	67/19	532	77	0.98	0.86	0.43	0.47	5.0	5.0
STMicroelectronics (France)	519/11	544/10	603	486	0.86	1.12	0.69	0.93	6.0	6.6
Chartered Semiconductor (Singapore)	388/12	203/14	151	67	2.57	3.02	0.22	0.18	3.9	3.8
Amkor Technology (U.S.)	326/13	64/20	76	21	4.29	3.10	0.22	0.46	4.9	5.3
National Semiconductor (U.S.)	310/14	316/12	208	197	1.49	1.60	0.64	1.28	5.5	5.8
United Microelectronics (Taiwan)	297/15	640/9	286	379	1.04	1.69	0.10	0.14	3.6	3.8
Xilinx (U.S.)	282/16	240/13	146	94	1.93	2.56	1.80	1.42	5.1	5.5
Lam Research (U.S.)	259/17	161/15	107	63	2.42	2.57	0.33	1.38	6.1	6.5
Conexant Systems (U.S.)	256/18	85/17	143	60	1.79	1.42	0.64	0.85	5.6	4.6
Macronix International (Taiwan)	198/19	71/18	123	28	1.61	2.51	0.13	1.30	3.5	5.1
Tessera Technologies (U.S.)	185/20	131/16	49	35	3.78	3.80	0.57	0.48	10.3	8.6
TELECOMMUNICATIONS										
Ericsson (Sweden)	1,197/1	1,146/3	767	567	1.56	2.02	0.94	1.08	5.6	5.5
Motorola (U.S.)	1,120/2	1,955/1	778	1,178	1.44	1.66	1.64	0.88	5.4	5.4
Lucent Technologies[6] (U.S.)	1,035/3	1,938/2	690	1,101	1.50	1.76	1.40	1.51	4.7	5.5
Nokia (Finland)	834/4	470/6	439	258	1.90	1.82	0.48	0.50	5.1	5.3
Nortel Networks (Canada)	822/5	679/4	459	333	1.79	2.04	1.69	0.91	4.7	4.7
Qualcomm (U.S.)	631/6	453/7	203	108	3.11	4.19	0.84	1.10	7.4	6.5
AT&T (U.S.)	621/7	647/5	293	230	2.12	2.81	1.13	1.12	5.2	4.6
Alcatel (France)	498/8	413/8	445	366	1.12	1.13	0.68	0.86	5.7	6.5
Agere Systems (U.S.)	432/9	88/14	419	75	1.03	1.18	1.30	1.30	5.1	5.1
JDS Uniphase (U.S.)	322/10	167/13	145	87	2.22	1.92	2.44	2.61	6.5	6.9
Verizon Communications (U.S.)	321/11	307/9	87	94	3.69	3.26	1.62	1.45	5.6	6.1
WorldCom (U.S.)	299/12	220/10	109	88	2.74	2.51	1.18	1.09	4.4	4.7
Nippon Telegraph and Telephone (Japan)	159/13	194/11	113	131	1.41	1.48	1.44	2.02	6.1	4.9
Avaya (U.S.)	155/14	176/12	128	38	1.21	4.60	0.32	0.17	6.3	6.0
Ciena (U.S.)	153/15	59/15	39	15	3.92	4.04	0.92	1.95	5.0	4.6

Indexing Innovation

Technology Review has teamed with CHI Research of Haddon Heights, NJ, to produce the Patent Scorecard, an industry-by-industry ranking of corporate patent portfolios. CHI combines the number of patents a company receives with other indicators to flesh out this deeper picture of innovation. Here are the specifics:

TECHNOLOGICAL STRENGTH: This figure, the basis of the rankings, provides an overall assessment of a company's intellectual-property power. It is calculated by multiplying the number of a company's U.S. patents by its Current-Impact Index *(see below)*.

NUMBER OF PATENTS: This total equals the number of U.S. patents awarded, excluding design and other special-case inventions.

CURRENT-IMPACT INDEX: This measure showcases the broader significance of a company's patents by examining how often its U.S. patents from the previous five years are cited as prior art in the current year's batch. A value of 1.0 represents average citation frequency, so, for example, a value of 1.4 would indicate a company's patents were cited 40 percent more often than the average.

SCIENCE LINKAGE: Some patents cite scientific papers as prior art. This value shows the average number of scientific references listed in a company's U.S. patents. A high figure indicates a company closer to the cutting edge than its competitors with lower values.

TECHNOLOGY CYCLE TIME: This indicator of a firm's speed in turning leading-edge technology into intellectual property is defined as the median age (in years) of the U.S. patents cited as prior art in the company's patents.

1. Unless otherwise noted, figures for each company include all subsidiaries and wholly owned companies. In some cases, subsidiaries would have made the list independently.
2. These figures are averages that cover a five-year span.
3. This excludes figures for Genentech, which is wholly owned by Roche.
4. This excludes figures for Syngenta, which is wholly owned by Novartis.
5. Nektar Therapeutic was formerly Inhale Therapeutic Systems.
6. This excludes figures for Avaya, which is wholly owned by Lucent and is listed separately on the scorecard.

An expanded version of the scorecard lists more companies and is available at http://www.technologyreview.com/scorecards/.



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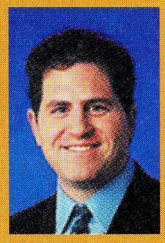
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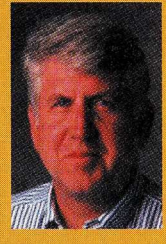
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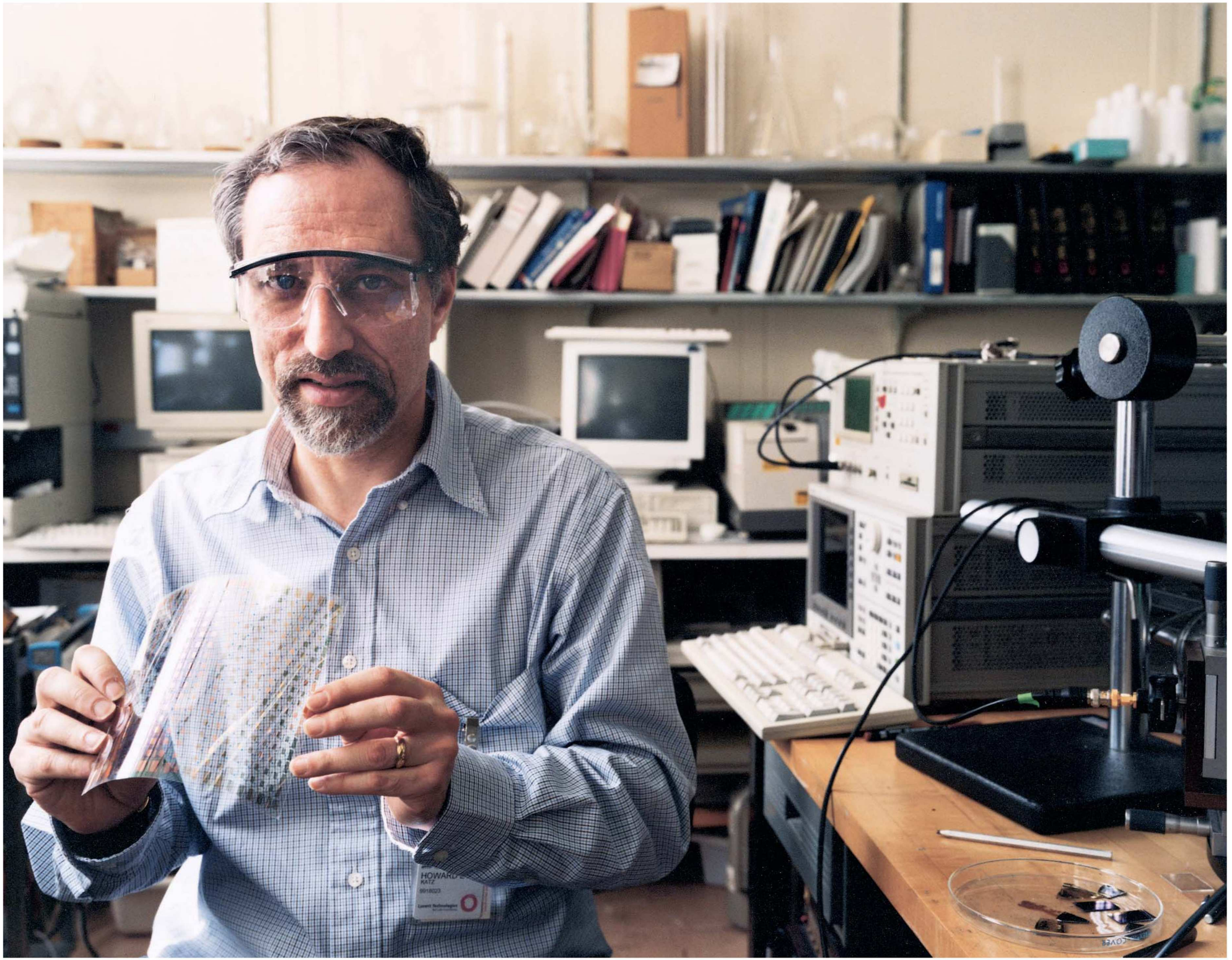
THE PRINTABLE TRANSISTOR

Bell Labs revolutionized electronics with the invention of the transistor. **Howard Katz** hopes to repeat the feat with some fancy chemistry.

Photographs by Beth Perkins

A half century ago, researchers at Bell Labs in Murray Hill, NJ, changed the world with their introduction of the transistor. Since then, the devices have evolved, becoming smaller, faster, and ubiquitous—finding their way into everything from computers to toasters. But today's silicon transistors are still too expensive or inflexible for some applications. Howard Katz and his colleagues at Lucent Technologies' Bell Labs hope to solve these problems using not silicon but organic chemistry.

Organic semiconductors, Katz says, would be cheap, easy to manufacture, and printable on flexible plastics that could easily cover large, irregular areas. "If you can't take advantage of one of those attributes, then you may as well use a silicon chip," Katz says. The materials already have been used to create electronic paperlike prototypes—cheap, bendable display surfaces that could one day replace paper. Organic transistors might also be used in toys, sensors, or in the best-case scenario, radio frequency identification tags—a sort of price tag of the future—that could instantly relay inventory and purchase information to a store's computers. But commercial use of organic semiconductors is still several years off, Katz says. "Every part of this needs more research—making it reliable, being able to make a process that you can do over and over again with available equipment, doing it on materials that are flexible." In his lab, Katz took *Technology Review* senior associate editor, Erika Jonietz, through the process of testing one of dozens of compounds he and his team are developing.



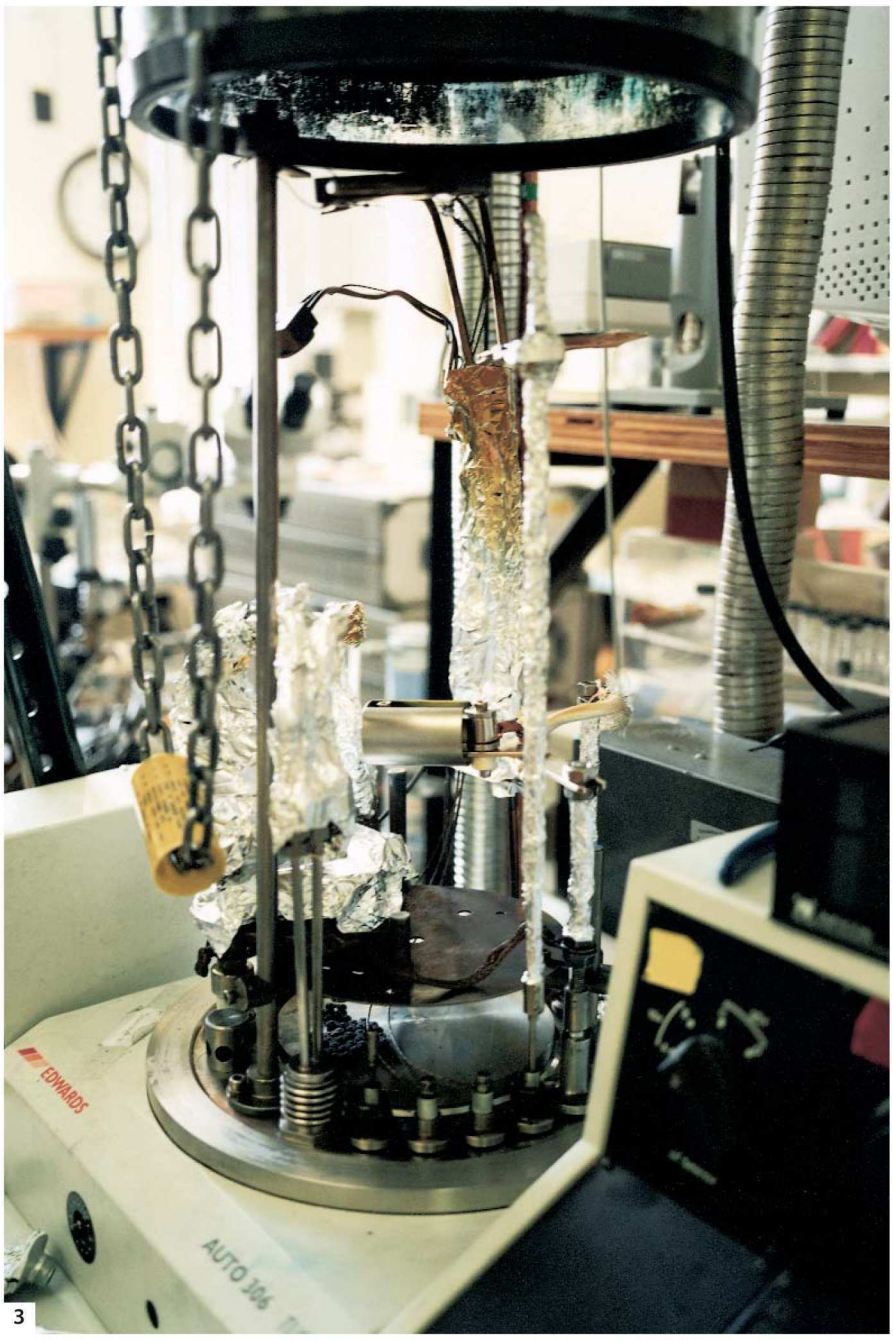


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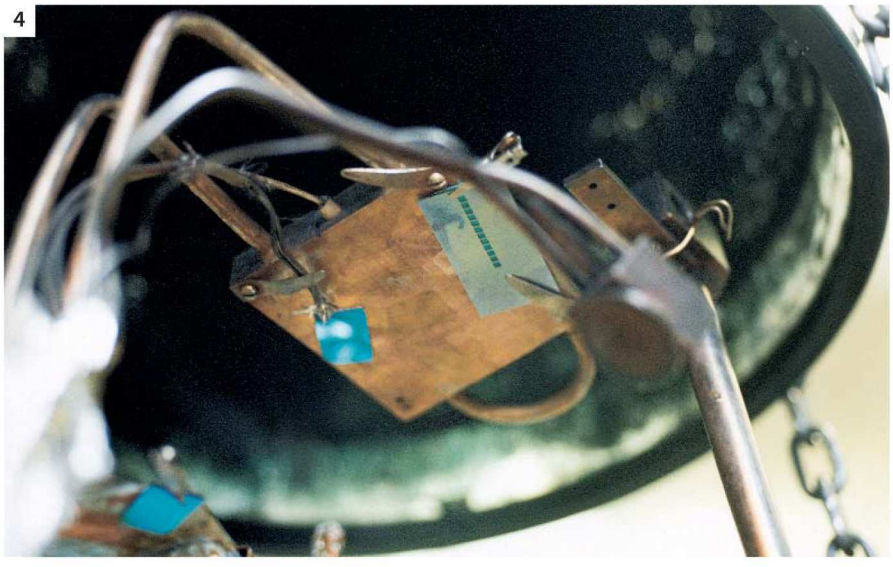
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1-2. Though prototype transistors have been made using organic semiconductors, researchers are still hunting for better compounds. Katz has formulated and tested nearly 100 materials in the 10 years since he started the project. "Designing these compounds, you have to design for the electrical properties and also for how they would behave in the process you want to use," Katz says. Today he is testing a new compound *(1)* by using vapor deposition to lay down a thin film of the polymer on a test surface *(2)*. He loads a small amount of the material into a chamber, creates a vacuum, and slowly heats the sample. "Once it gets hot enough, it will evaporate," Katz says. "Then the vapor will land on every surface inside."

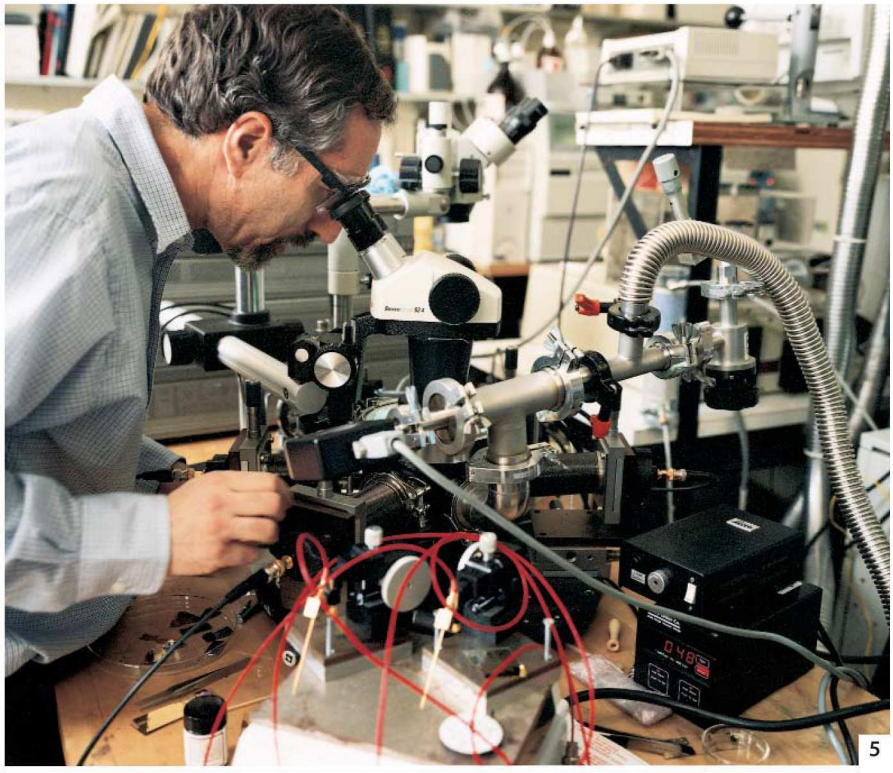


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3-4. After the polymer coats the small silicon chips Katz is using as test surfaces, he lets nitrogen into the chamber to release the vacuum and raises the cover *(3)*. He points out a gold-colored compartment, a part of the heating system into which he had placed the organic compound at the start of the process. The three chips Katz has clamped at the top of the chamber *(4)* are now blue because of the organic film. "You only need about 10 nanometers of the film to have current," Katz says. "We actually put 50 nanometers to make sure there aren't any gaps or holes." To test different conditions, the left-most chip was not heated, while the other chips were. The chip on the far right is covered with a stencil to create isolated areas of film.

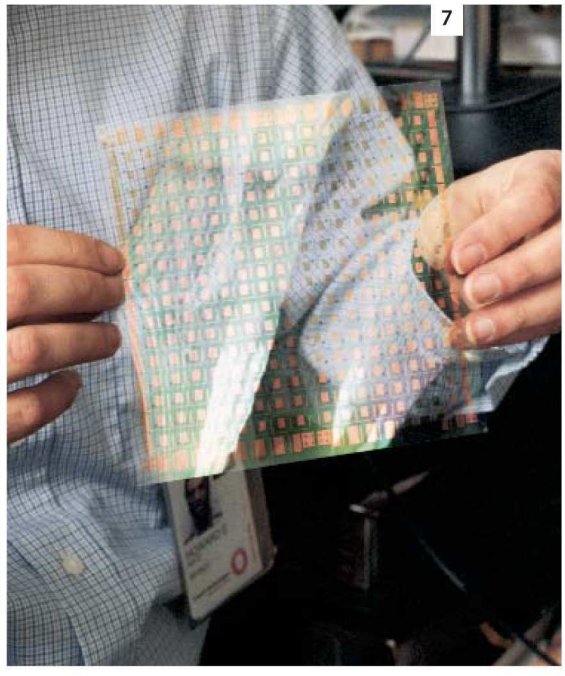


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5-6. The semiconductor films are patterned with gold in a second round of vapor deposition. "These gold stripes are all contacts for probing the material's electrical properties," Katz says. "This is where we see whether a compound we make really is a semiconductor or not." He uses a microscope to observe the test process *(5)*. "We touch these stripes with needlelike probes," he says *(6)*. "Then we put voltages through them and measure what happens as a result." If the compound is a good semiconductor, Katz's team will work on simpler methods for making films from it. For instance, they have dissolved some compounds in solvents and simply dripped the solutions onto test surfaces using eyedroppers. "That's closer to what we ultimately want to do," Katz says. "There's a lot that we don't understand about the process of how that happens. But the devices still work." The gold stripes, he adds, would be replaced by conductive ink that could be patterned using, say, ink-jet printers.

7. Although Katz is still developing organic semiconductor materials, the team, including Zhenan Bao and Christian Kloc, has already created experimental transistors on plastics using vapor deposition and the dropper method to pattern the semiconductor. "Ultimately, we just want to be printing," Katz says. "But we have to test each material along the way." Those careful tests will help pave the path to a cheap, flexible alternative to silicon. TR



7

By Carl S. Kaplan | Photograph by Emily Nathan

CURBING PEER-TO-PEER PIRACY

Pamela Samuelson

POSITION: Professor of Law and Information Management and Codirector, Berkeley Center for Law and Technology, University of California, Berkeley

ISSUE: Fighting file sharing. Copyright owners are using technology, as well as the legal system, to combat users who share music and video files over peer-to-peer networks like KaZaA and the defunct Napster.

PERSONAL POINT OF IMPACT: Principal organizer, 2003 Law and Technology of Digital Rights Management Conference; board member, Electronic Frontier Foundation

TECHNOLOGY REVIEW: Is sharing music on peer-to-peer networks really piracy?
PAMELA SAMUELSON: Prior to the Napster decision in February 2001, which held that users who swapped music files via peer-to-peer technology were copyright infringers, it was possible to argue that people who were doing file sharing on a noncommercial basis were engaged, at least many of them, in fair uses. If that was true, then one could make the argument that these peer-to-peer file-sharing technologies had substantial noninfringing uses. After the decision, it's not so easy to argue that the underlying act of file sharing is lawful. So you have to say a lot of people who are doing file sharing are engaged in copyright infringement.

TR: How much damage is this kind of infringement doing?
SAMUELSON: The question of harm from the kind of file sharing that's happened so far is widely debated. If you think that every unauthorized copy is a copy that should have a commercial value attached to it and the failure of the copyright owners to get that particular value is a harm to their market, then it's easy to multiply the number of illicit copies times the value of whatever was shared and say, Oh, a kazillion kazillion kazillion dollars. However, a number of economists have looked at this and said, Gee, you know, it's not so convincing that that actually is a fair interpretation—that there's been substantial harm. Even if there's been some harm, there has been a lot less harm than the copyright industries are claiming.

TR: What kinds of things are copyright owners doing to fight file sharing?
SAMUELSON: Copyright owners right now are using phony files, decoys, and other chaff to try to frustrate the experience on peer-to-peer networks, where users share files. For instance, it could be a file with the name of the latest Madonna song, but when a person opens it and tries to listen to it, it might contain something that says, You've just engaged in copyright infringement; this is illegal; you're harming the artist; don't do it anymore. The theory is that if you make peer-to-peer file sharing an unpleasant experience where users can't always get what they want, then people will stop. However, use of such chaff in the network seems not to be working very well. So the copyright industries want Congress to do something to help them step up the attack on file sharing.

TR: Last July U.S. Congressman Howard L. Berman (D-CA) introduced a bill, the Peer-to-Peer Piracy Prevention Act, to help copyright owners battle illegal file sharing. He hasn't decided whether to reintroduce the bill, but it's an interesting example of such legislation. How would it help copyright owners?
SAMUELSON: The bill would essentially provide immunity to copyright owners who disable, interfere with, block, divert, or otherwise impair some acts of copyright infringement that are happening via publicly accessible peer-to-peer file-trading networks.

TR: How would they do that?
SAMUELSON: Well, suppose you've got somebody who has a thousand songs on his hard drive and all of them are available to others for downloading. That person makes a tempting target for a recording-industry attack. It may be possible to engage in a kind of denial-of-service attack by bombarding the supernode with messages so that it has to go down. Or it may be possible to tie up the node with slow-motion downloading and block out other users.

My sense is that this bill would not just immunize this kind of interference with downloading; it also would immunize more aggressive acts, including those that would otherwise violate the Computer Fraud and Abuse Act [CFAA] and the Digital Millennium Copyright Act's anti-circumvention provisions. The CFAA has quite a lot of open-ended provisions. For example, if a rights holder accessed a user's computer and disabled use of files on that computer, that would violate CFAA. As the recording industry was contemplating how to fight back against peer-to-peer file sharing using technology, they correctly reasoned that they might, in fact, be subject to liability under the broad provisions of the CFAA or other federal or state laws that forbid, for example, trespassing on somebody else's computer system.

TR: The bill's advocates say it would permit "self-help," a venerable legal concept. For instance, everyone knows that the repo man can come and repossess your car if you don't make the payments. Why isn't this a good tool for combating piracy?
SAMUELSON: Self-help of the kind we talked about earlier—putting some chaff into the system—seems to me to be perfectly appropriate because it doesn't otherwise violate the law or public policy. But when somebody wants to repossess a car, he can't break into your garage in order to get the car. And the analogy holds when you talk about computers. Why should the recording industry be able to hack into a person's computer? The target of the attack may have a considerable amount of information on his or her computer other than some infringing files. The damage that this bill would allow copyright owners to do to information on a person's computer may be not only to those files that they,



arguably, have a right to do something about; the attack may have spillover effects.

TR: You think the Berman bill overreaches?
SAMUELSON: Oh, yes. Even if you have a lot of sympathy, which many people do, for the copyright industries, the use of a set of techniques that's going to have substantial negative spillover effects for the security of computer networks seems to be at odds with other really important public policies that are being developed. One of the really unfortunate consequences is that just as we've been trying to increase computer security and to diminish the extent to which networks have been disrupted in the last year or so, you have one industry asking for a grant of immunity to engage in what otherwise look like terrorist acts.

TR: So what alternatives are there if we want to protect both copyrights and individual rights?
SAMUELSON: If the goal is compensation to artists, then it may be time, especially in view of how widespread file sharing is, to start thinking seriously about some sort of licensing scheme so that noncommercial file sharing, for example, could be made profitable for copyright owners. But it would be necessary to impose some sort of tax. This would get copyright holders some money and would stop the punitive war that has been going on, which is going to be really tough for the industry to win.

TR: How would such a tax work?
SAMUELSON: People who engage in file sharing usually want broadband Internet access, so Congress could put a tax on the bandwidth access and then distribute that money to copyright owners based on some sampling done about file sharing that estimates how the money should be distributed. Or it could tax hard drives, CD burners, or file-sharing software.

I don't think that there's one silver bullet that solves the whole problem. But it's important to find some solution that is the least socially disruptive—one that also then gets a wide array of wonderful creative works into the hands of lots of different people. Because that's what ultimately the copyright system is supposed to achieve.

For an expanded version of this interview, go to www.technologyreview.com/impact/.

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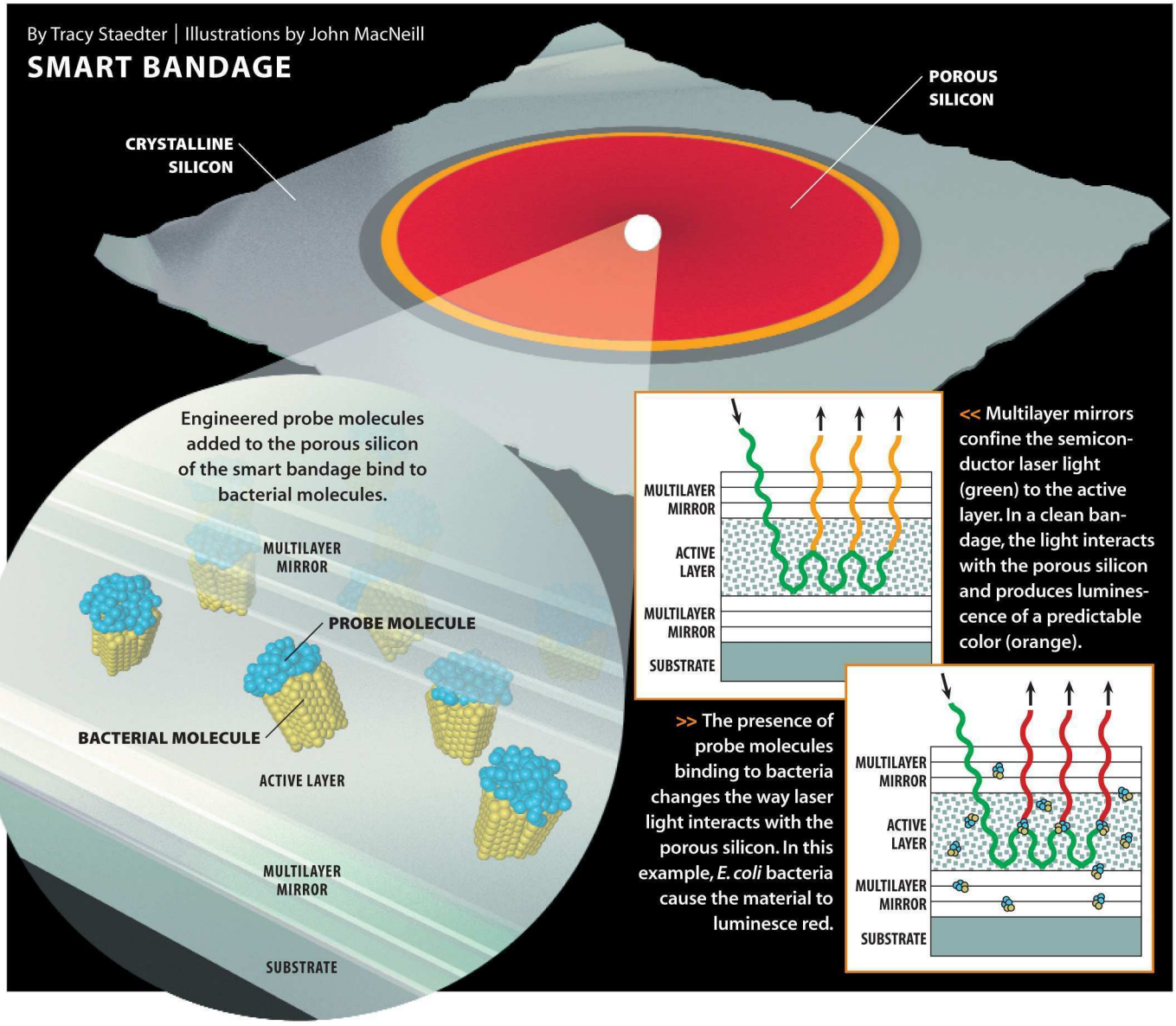
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By Tracy Staedter | Illustrations by John MacNeill

SMART BANDAGE



Dressing a wound may stop the bleeding, but it can't tell you whether the cut has become infected. Now "smart" bandages being developed at the University of Rochester change color not only to warn patients and doctors that there is an infection, but also to specify which bacteria are present.

The smart bandage is a thin sensor made of crystalline silicon and layers of porous silicon. The porous silicon is treated with a liquid that contains probe molecules engineered to bind to fat molecules found on the surface of specific bacteria. When the bandage is placed over an infected area, bacteria from the wound move into the porous silicon and attach themselves to the probe molecules, altering the optical properties of the silicon. Doctors illuminate the bandage with light from a handheld semiconductor laser device, and the bandage luminesces in a color that indicates the kind of bacteria that are present—red for *E. coli*, for example, or yellow for strep. With the immediate diagnosis of the culprit germs, doctors won't have to wait for the results of laboratory cultures.

Researchers at the University of California, San Diego, are working on similar sensors. Refinements to the technology should help smart bandages make their way into hospitals within a year or two as sensors embedded in the mesh of standard dressings. But you may see them popping up elsewhere sooner. The same technology could be applied to meat wrappers and other food packaging, which would show a warning color upon detection of foodborne bacteria. Such sensors could also be affixed to drinking glasses that would check for water purity or indications of biowarfare. Bandages aren't just for skinned knees anymore. TR

For an animated version of this illustration, go to www.technologyreview.com/visualize/.

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THE VISION THING

Patent lawyers, like undertakers, generally have the decorum not to gloat when business is good, but, boy, these days it must be hard for them to keep quiet. Lately, there seem to be more patent lawsuits under way or threatened than at any other time I can remember. And that leads me to wonder, Don't the companies filing these lawsuits have anything better to do?

The obvious answer is yes, they do. Despite difficult economic times, today's high tech companies need to remember their core mission: to bring better products and services to market. Innovation and problem solving play central roles. Equally important is how these organizations pick the problems they will address. With that in mind, I interrupt my normally scheduled program—exposing intellectual-property shenanigans—to bring you a hopeful message about creative problem solving.

As a case in point, I give you physicist Joshua Silver. A University of Oxford experimentalist and self-described "tinkerer," Silver had a successful academic career in atomic physics, as well as consulting work for the Lawrence Livermore National Laboratory. With a good working knowledge of optics and, as he says, "the hopes of making piles of money," he undertook some commercial research in the mid-1990s with cosmetics maker Estée Lauder: development of a cheap mirror a user could adjust to magnify his or her reflection.



One billion people worldwide can't afford corrective lenses. Efforts to devise cheap adjustable eyeglasses show that what matters most isn't what you invent, but what you do with your invention.

While he was experimenting with prototypes of mirrors and lenses, Silver found a way to adjust the lenses' focus. By varying the amount of silicone oil between two flexible membranes, Silver realized he could effectively change their curvature. The potential for his research hit home when he took off his own glasses (Silver is myopic) and discovered he could see clearly through his crude lenses.

At about the same time, Silver came across astounding information that helped him refocus his own research goals: an estimated one billion people in the developing world have uncorrected vision. They are nearsighted, farsighted, or in need of reading glasses, and they cannot afford or don't have access to eyeglasses. Up to half of Americans and Europeans wear corrective lenses, but few people in the developing world do.

To his immense credit, Silver realized his research on lenses could help solve a huge global health problem. He decided to stop working for the cosmetics firm and set his sights higher. He would develop cheap adjustable eyeglasses and bring corrected vision to the enormous number of people in need. Silver recognized that a company set up to deliver these eyeglasses could both pursue a laudable goal and be financially viable. "Once I saw I could do something about this problem, I came to realize that I really should go out and give it a go," he says.

Today, Silver heads Adaptive Eyecare, a privately held Oxford, England-based startup. Although he has secured scores of patents on his invention, Silver has directed his company's attention to making his adjustable eyeglasses as widely available as possible. To that end, Silver believes he can bring the cost of production below a dollar per pair. Adaptive Eyecare is in discussion with the World Health Organization, the governments of several African countries, retailers, and nonprofit organizations to figure out the best way to distribute the eyeglasses to 10 million people in Ghana and southern Africa.

Adaptive Eyecare's early eyeglasses are thick and clunky. But by pumping silicone oil into their spectacles, people can adjust them until they get the prescriptions that are just right for their eyes. Because they are adjustable, Silver's eyeglasses eliminate the need for an exam by an optometrist and the costly infrastructure of a staffed lens-grinding facility to prepare individual prescriptions.

As Silver notes, the lack of such expertise and facilities in poor countries has presented a nearly insurmountable obstacle to widespread dissemination of corrective eyeglasses—barriers that would remain even if the production cost for conventional glasses could drop to zero. In a recent report, the company contends that the adjustable lenses can correct vision with accuracy approaching that of those made with traditional methods. Now it's mainly a question of refining the technology and taking it to the people who need it. The company has tested the eyeglasses in a successful field trial that involved several hundred people in Ghana, and it plans to ramp up production to 100,000 pairs per month by year's end.

Silver is not alone in his efforts. Low Cost Eyeglasses—a Washington, DC-based company, founded by MIT doctoral candidate Saul Griffith and Harvard Business School graduate Neil Houghton—aims to bypass the need for qualified optometrists in developing countries by distributing an inexpensive eye-testing device that checks eyesight, as well as a plastic eyeglass mold that forms corrective lenses on site.

Both efforts are impressive and inspiring for their genuine innovation, their message about how much one person or group can do to instigate positive change, and, perhaps most of all, for the creative way they have tried to tackle a pressing global problem. Not only that, but it looks as though the two companies—even with their public-spirited missions—can become profitable businesses. Maybe their experiences can encourage the companies that sue one another over broad proprietary rights to tomorrow's technology to elevate their goals and recognize that they have a choice about how and where they direct their prodigious research efforts. TR

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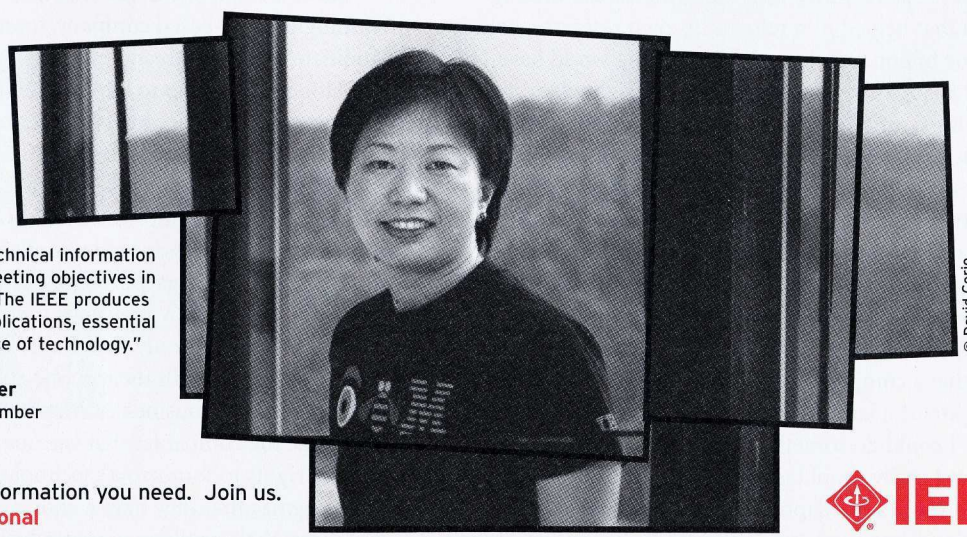
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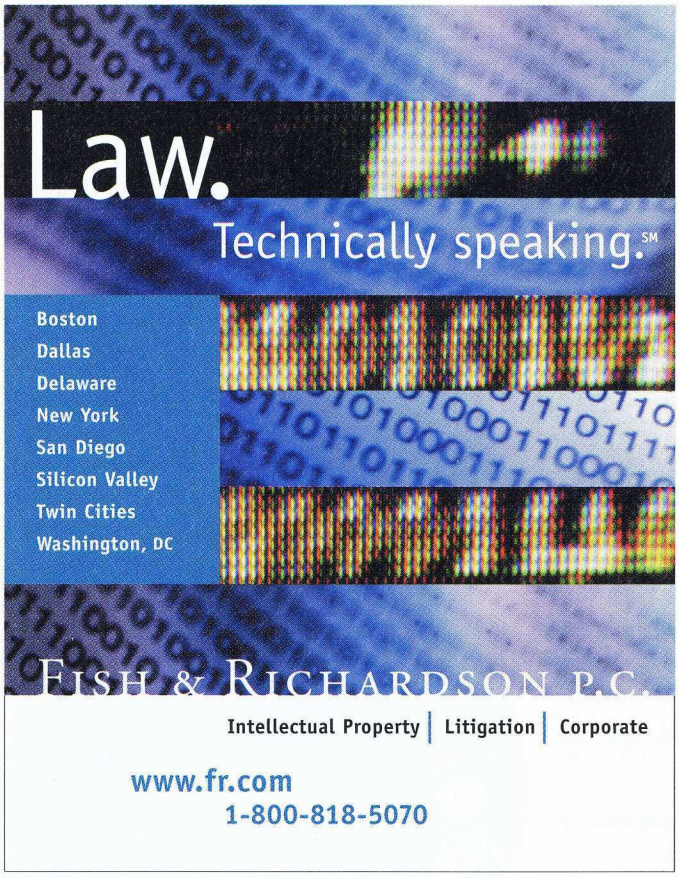
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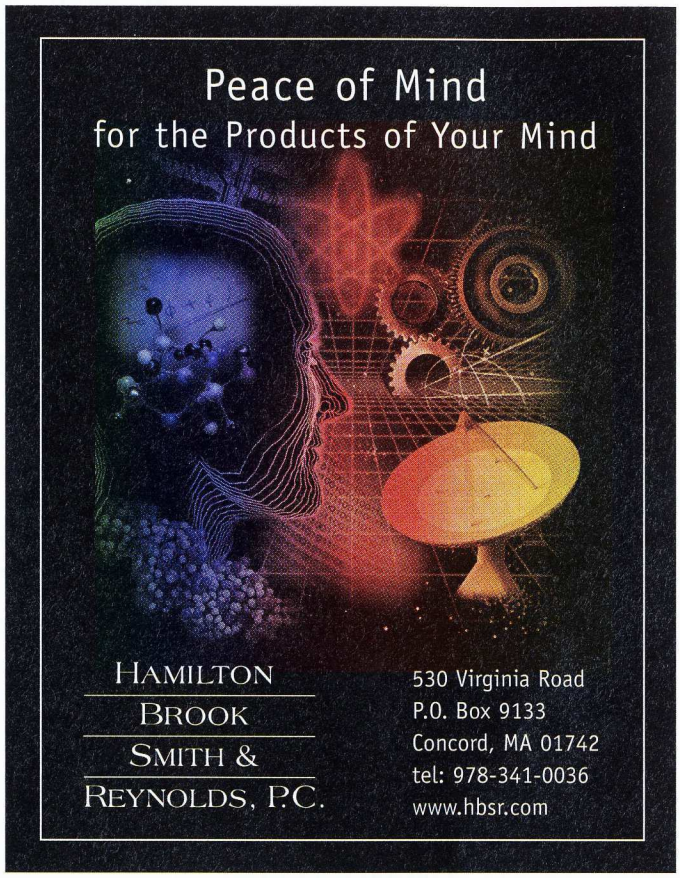
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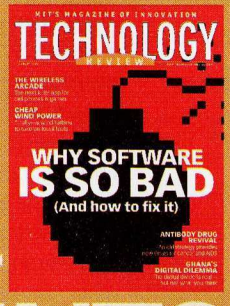
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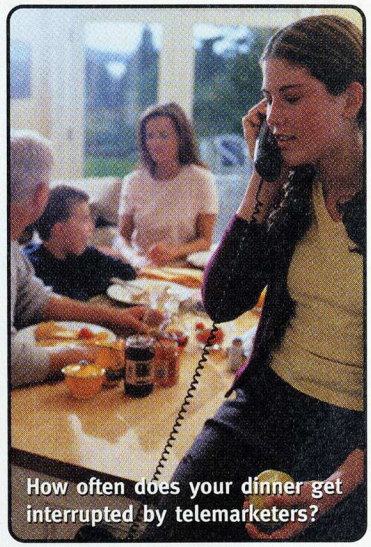
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PHYSIOLOGY'S HIDDEN GENIUS

A pioneering female researcher journeys from the factory to the laboratory

In the early part of the 20th century, biologists were just beginning to investigate the chemical reactions that occur within cells. Ida Hyde's invention of the microelectrode, a device essential to the study of muscle and brain cells *(see "Mind-Machine Merger," p. 38)*, was a landmark achievement, but she was not recognized for the invention in her lifetime.

As a teenager in the 1870s, Hyde helped support her family by working as an apprentice at a Chicago clothing factory. In spite of her family's disapproval, Hyde's ambitions were in academia, not women's wear. After years of night school classes, Hyde was accepted at Cornell University. She earned a bachelor's degree in biology in 1891 and continued with graduate work at the Woods Hole Marine Biological Laboratory.

The young scholar gained international attention when her research on octopus embryos settled a controversy between two European biologists. That achievement led to her admission to the University of Heidelberg in Germany. Because Hyde was a woman, she was prohibited from attending certain lectures and had to learn from other students' notes. She returned to the United States in 1896 to become the first female researcher at Harvard Medical School.

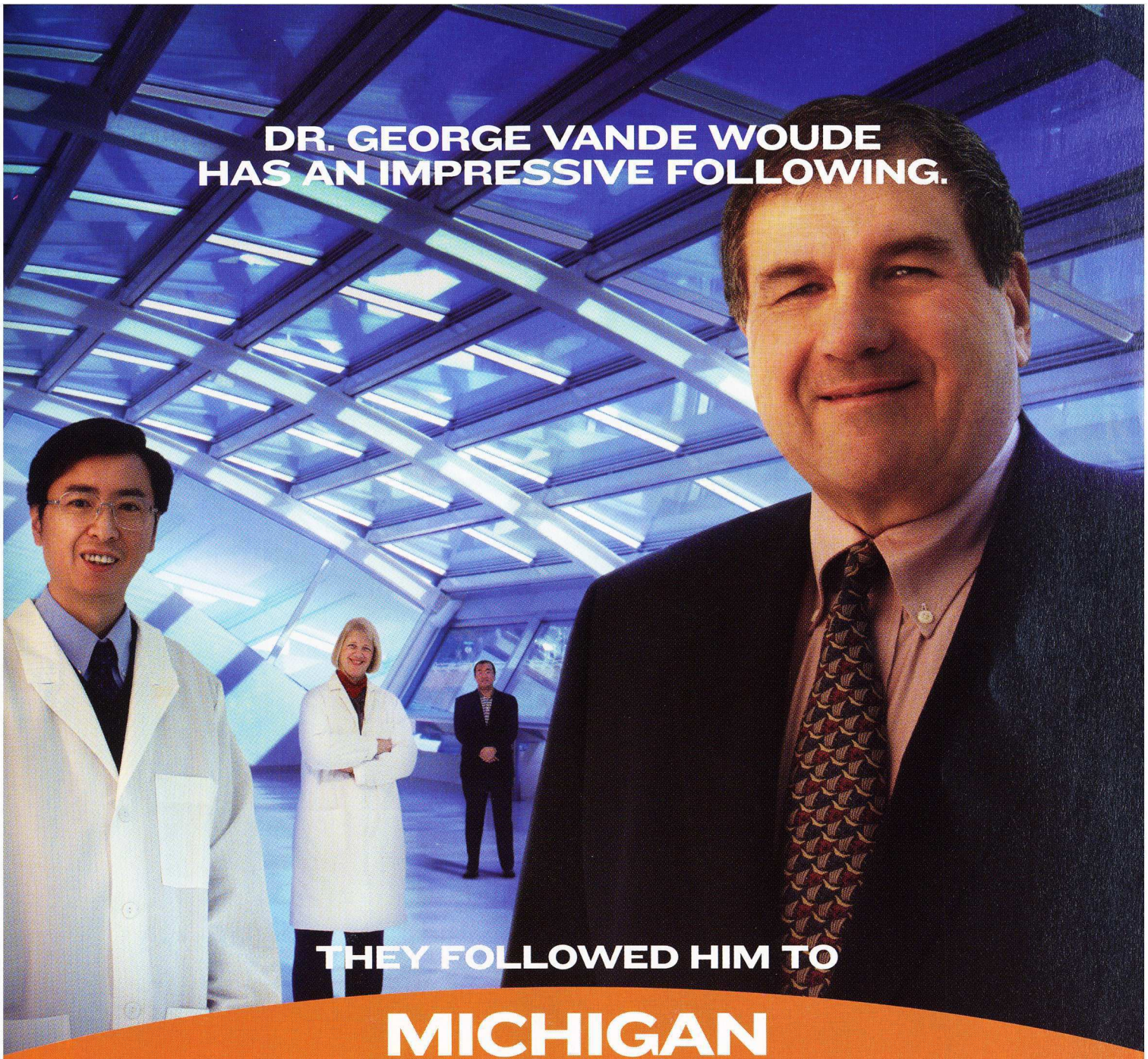
Hyde's research caught the attention of University of Kansas chancellor Francis Snow, who hired her to build the school's physiology department. During her tenure there, Hyde studied the respiratory, circulatory, and nervous systems of a wide range of organisms, from grasshoppers to humans. Greatly concerned about public health and women's education, she also lectured throughout the Midwest about sexually transmitted diseases, using nude Greek statues as models.

Hyde accomplished her most impressive scientific achievement at the end of her career in 1918. While studying single-celled organisms, she developed a device that could inject or remove substances from individual cells and simultaneously stimulate the cells electrically. The technique, which Hyde reported in 1921, would revolutionize physiology. Today microelectrodes are used to monitor electrical impulses in the brain. It wasn't until the microelectrode was reinvented 20 years later by Judith Graham and Ralph Gerard of the University of Chicago—apparently with no knowledge of Hyde's earlier work—that the invention took off.

Although Hyde received no attention for her ingenious device, her legacy lives on. The University of Kansas continues to award scholarships from a fund she established to create opportunities for women in biology. *—Lisa Scanlon*

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